Feasibility Study and Optimal Design of Hybrid Renewable Energy Microgrid System for Rural Electrification in Ethiopia (A Case Study: Jimma-Gera-Kola-Kinibibit)

Chernet Gebre Kefelegn

A Thesis Submitted to the Department of Electrical Power and Control Engineering,

School of Electrical Engineering and Computing

Presented in Partial Fulfillment of the Requirement for the Degree of Master in Power and Control Engineering (Power Engineering)

Office of Graduate Studies

Adama Science and Technology University

July 2023

Adama, Ethiopia

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DECLARATION

I hereby declare that this Master Thesis entitled "**Feasibility Study and Optimal Design of Hybrid Renewable Energy Microgrid System for Rural Electrification in Ethiopia**" is my original work. That is, it has not been submitted for the award of any academic degree, diploma, or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation

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RECOMMENDATION OF ADVISORS

I/we, the advisor(s) of this thesis, hereby certify that I/we have read the revised version of the thesis entitled " **Feasibility Study and Optimal Design of Hybrid Renewable Energy Microgrid System for Rural Electrification in Ethiopia**" prepared under my/our guidance by Chernet Gebre Kefelegn submitted in partial fulfillment of the requirements for the degree of Master of Science in Electrical Power and Control Engineering (Stream Power Engineering). Therefore, I/we recommend the submission of a revised version of the thesis to the department following the applicable procedures.

Dr. Milkias Birhanu		07/07/2023
Major Advisor/Supervisor	Signature	Date
Co-advisor/Co-supervisor	Signature	Date

APPROVAL PAGE OF M.Sc. THESIS

I/we, the advisors of the thesis entitled "**Feasibility Study and Optimal Design of Hybrid Renewable Energy Microgrid System for Rural Electrification in Ethiopia**" and developed by Chernet Gebre Kefelegn; hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

Milkias Birhanu
_______________ _______________ _______________
Major Advisor Signature Date

_______________ _______________ _______________
Co-advisor Signature Date

We, the undersigned, members of the Board of Examiners of the thesis by Chernet Gebre Kefelegn have read and evaluated the thesis entitled "**Feasibility Study and Optimal Design of Hybrid Renewable Energy Microgrid System for Rural Electrification in Ethiopia**" and examined the candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Electrical Control and Power Engineering (stream Power Engineering).

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LIST OF ACRONYMS AND ABBREVIATIONS

AC	Alternative Current
ADF	average daily flow
AF	axial flow
ANFIS	Adaptive network-based fuzzy inference System
AVR	Automatic Voltages regulator
BESS	Battery Energy storage system
CC	Cycle charging
CFL	Classroom light
CO2	Carbon dioxide
COE	cost of energy
DC	Direct Current
DC-DC	DC-to-DC Converter
DERs	Distributed energy resources
DG	Diesel Generator
DOD	Depth of Discharge
DODmax	Maximum Depth of Discharge
DOE	Department of Energy
EEP	Ethiopia Electric Power
EEU	Ethiopia Electric Utility
ESSs	Energy storage systems
PV	Photovoltaic
GHI	Global Horizontal Irradiance
GPS	Global Positioning Systems
H-net-Net	net Head
HH	Household
Home-Pro	hybrid optimization of multiple energy resources -Pro
HOMER	hybrid optimization of multiple energy resources
HVD	high voltage disconnection
LED	Light Emitted Diode
LF	Load following
LP	liquid propane
LVD	low voltage disconnection
MCCB	Molded case Circuit Breaker
MHP	Micro-Hydro Power
MoWE	Ministry of Water and Energy of Ethiopia
MP	maximum power
NASA	National Aeronautics and Space Administration
NPC	Net present cost
NREL	National Renewable Energy Laboratory
PTC	Power test Condition
PV	photovoltaic
PVsyst	Photovoltaic System
RLC	Resistance -Inductance-capacitance
SEPIC	single-ended primary inductor converter
STC	Standard Test Conditions
THD	Total Harmonic Distortion
VMP	Maximum voltage

ABSTRACT

The introduction of a decentralized energy system in rural areas with limited or no access to electricity can improve the quality of life of people living in rural areas. Renewable energy technology plays a key role in electricity generation, as grid expansion is not cost-effective. This study mainly focused on the techno-economic feasibility and optimal design of a hybrid power system ,or the combination of micro-hydro-photovoltaic-diesel-battery-power system designed to electrify a typical remote village in southwest Ethiopia, which was called the Kola-Kinibibit kebele. It aims to achieve electrification at a low cost by considering the complexities of environmental pollution emissions. Therefore, this study determines the technical details and economic feasibility of setting up such a power system using the hybrid optimization of multiple energy resources (HOMER-PRO) simulation tool. Different combinations of energy resources, such as solar, hydro, energy storage systems, and diesel generators, were compared and analyzed. The system performance and economics used determinant factors such as the cost of energy, operation and maintenance costs, net present costs, excess electricity, capacity shortage, generator fuel consumption rates, load fulfillment, CO2, and other pollutant gas emission savings. The results and comparative analysis show that a hybrid hydro/PV/diesel/battery system is the preferred option for off-grid rural electrification with a solar power capacity of 45.1KW dc power, micro-hydropower capacity of 73.3KW, and a 15 kW diesel generator. The simulation results also indicate that the optimal system had a net present cost (NPC) and cost of energy (COE) of $862,098 and $0.0966/kWh, respectively, with a renewable fraction of 99.1%, excess electricity of 11.6%, and required initial capital of $375,151. Finally, to efficiently use the energy produced using the energy sources mentioned above installed as an island microgrid system, a fuzzy logic controller is used to make an intelligent decision by identifying the type and amount of resources available, then choosing the appropriate alternative source and implementing it. The fuzzy rule was written using a fuzzy rule editor, and each component of the proposed and entire hybrid system was modeled using MATLAB/Simulink.

Key words: *Mini-hydro, PV, Diesel generator, HomerPro, MATLAB/Simulink.*

CHAPTER ONE

1. INTRODUCTION

1.1 Background of the Study

Access to energy is a critical driver of social, economic and sustainable development for any country. It plays an important role in carrying out people's daily activities such as cooking, lighting, heating, Transportation, etc. This means that electricity is a basic requirement to sustain our industrial, commercial, and to some extent agricultural activities. It can play an important role in reducing poverty, soil degradation, and deforestation, as well as improving health care and living standards (Teshale, 2012).

The lack of access to electricity in rural areas is a significant problem in many developing countries. According to the International Energy Agency, over 600 million people in sub-Saharan Africa alone lack access to electricity, and many more lack reliable access. This lack of access to electricity has significant social, economic, and environmental consequences, as it limits opportunities for education, healthcare, and economic growth, and contributes to poverty and environmental degradation. Microgrid energy systems offer a promising solution to the challenge of rural electrification. Micro-grid is small-scale, localized energy systems that can operate independently or in parallel with the main electrical grid. They typically incorporate renewable energy sources such as solar, Biomass, micro-hydropower, and wind power, as well as energy storage systems and backup generators.

Microgrid energy systems offer several advantages for rural electrification. First, it deployed relatively quickly and cost-effectively, compared to traditional grid expansion. This is particularly important in remote and rural areas where the cost of extending the main grid may be prohibitively high. Second, they can provide a reliable and resilient power supply, even in the face of disruptions to the main grid or extreme weather events. Third, they can promote the use of renewable energy sources, which can have significant environmental benefits and reduce dependence on fossil fuels. There are several challenges to implementing microgrid energy systems for rural electrification. These include technical challenges such as system design and integration, as well as social and economic challenges such as financing, community engagement, and capacity building. Nevertheless, microgrid energy systems have been successfully implemented in many rural areas around the world, demonstrating their potential as a viable solution for rural electrification. In recent years, there has been a growing interest in using microgrid energy systems for rural electrification, particularly in developing countries. Many governments, international organizations, and private sector actors have launched initiatives to promote the deployment of microgrid energy systems in rural areas. These initiatives typically involve a combination of technical assistance, financing, and policy support to help overcome the challenges of deploying microgrid energy systems in rural areas. Overall, microgrid energy systems offer a promising solution to the challenge of rural electrification. By providing a reliable and resilient power supply, promoting the use of renewable energy sources, and supporting economic and social development in rural areas, microgrid energy systems have the ability to change the lives of millions of people around the world.

Nowadays, the Ethiopian Government has therefore adopted a three-track strategy comprising a grid extension by Ethiopian Electric Power/ Utility (EEP/EEU), off-grid electrification, and promotion of new energy sources. However, this sector faced difficulty to electrify remote area communities, due to the country's topography, and the Expensiveness of connecting the main gridto the village households, and it looks for other options for these remote communities through micro-grids either single supply or hybrid from potential renewable energy resource, but it has not been that much implemented. It is obviously known, Ethiopia has huge renewable energy (Photovoltaic, Geothermal, Wind Energy, Biomass, and Micro-Hydro) resources and if these resources are effectively used the livelihood of its population will be improved.

Therefore, this research is devoted to investigating the potential renewable energy resources available in the Kola Kinibibit district, which consist of many households,s Primary School, small scale industrial, irrigation system, and health post in order to optimize hybrid systems through Homer Pro software corresponding to the study energy demand. In addition, designed the hybrid entire system in MATLAB Simulinkand distribute the hybrid energy system with a controllable load using islanded micro-grid-basedwith their operation time. Finally, to encourage government, private investors, and localcommunities to take advantage of these technologies.

1.2 Statement of the Problem

A significant percentage of the Jimma zone rural population lacks access to electricity, for instance, Kola-Kinibibit kebele is one of them, which has a negative impact on their quality of life and limits their economic opportunities. This lack of access to electricity is a major barrier to achieving development goals, including poverty reduction, improved health outcomes, and increased economic growth. Moreover, reliance on traditional sources of energy such as kerosene lamps and wood for cooking has negative environmental impacts, contributing to deforestation, air pollution, and climate change. This problem has significant social, economic, and environmental implications. Without access to electricity, Kola-Kinibibit kebele communities are unable to power essential services such as healthcare facilities, schools, and communication networks. This limits their educational and economic opportunities and contributes to a cycle of poverty. Moreover, the use of traditional sources of energy can have negative health impacts, particularly for women and children, who are often responsible for collecting firewood and cooking meals over open fires. Finally, the environmental impact of traditional energy sources can contribute to climate change, which has far-reaching effects on ecosystems and human societies. Addressing the lack of access to electricity in Kola-Kinibibit kebele is a complex challenge that requires a multi-faceted approach. This may involve expanding the electrical grid to reach the communities, promoting the use of renewable energy sources, such as solar, micro-hydropower, and diesel generator power, and improving energy efficiency in homes and public buildings. Grid expansion is not cost-effective; therefore, designing a decentralized microgrid energy system is preferable to avoid a lack of electricity for Kola-Kinibibit kebele communities. In addition, it may require addressing social and economic barriers, such as a lack of access to financing for energy projects and limited technical expertise. Overall, the lack of access to electricity in selected site is a pressing problem that requires urgent attention from policymakers, energy experts, and civil societies. By addressing this problem, we can ensure that all people have access to the basic resources necessary for a healthy, productive, and sustainable life.

1.3 Objective of the Study

1.3.1 General Objective of the Study

The general objective of this research is a feasibility study and the optimal design for a hybrid renewable energy microgrid system for Kola Kinibibit Kebele's communities.

1.3.2 Specific Objectives of the Study

The specific objectives include:

- To determine the present and near future needs for the electrical energy of the community living in the area.
- To evaluate the potential costs and benefits of implementing a hybrid renewable energy microgrid system compared to other options, such as grid extension or diesel generators.
- To decide the main components of backup system depending on the energy demand.
- To Evaluate the technical and economic performance, and size of the micro hydro-PV, energy storage, and diesel generator, and made sensitivity analysis using a tool (HOMER-PRO).
- To Model the hybrid entire system using MATLAB/Simulink and designed a fuzzy logic control system for hybrid power system.

1.4 Significance of the Study

The feasibility study and optimal design of a hybrid renewable energy microgrid system can have significant social, economic, and environmental benefits for rural communities. It can provide improved energy access, reduce energy costs, increase energy security, promote environmental sustainability, create jobs, improve health and safety, and promote technological advancement. Therefore, this study will give a solution by providing 24-hour electricity services to the community of Kola Kinibibit village if Ethiopia and other concerned bodies/governmental or non-governmental organizations work for the practical implementationof the project.

1.5 Delimitation of the Scope and Limitation of the Study

The study was conducted in southwest Ethiopia so called Kola-Kinibibit area for a year in order to serve 405 households, health posts, religious, and primary schools found the area as well as irrigation, small-scale industrial providing electricity, but there was no recorded public available data or data from a mentioned organization. The study is limited by the availability or accuracy of data, Technical limitations, limited by the availability of funding or resources to implement the microgrid system, limited by the acceptance or resistance of the community to the microgrid system, which could affect the feasibility and success of the project, and limited by external factors such as government policies, regulations, or market conditions that could affect the implementation of the microgrid system. There are also many limitations during carried-out the research investigation. That means this research will interpret only the optimization of the resource through Homer Pro software with its result based on net presentcost and the overall circuit diagram interpreted using MATLAB/Simulink.

1.6 Outline of the Thesis

This research paper consists of five chapters. The first chapter discussed the general introduction, statement of the problem, Objective of the study, the significance of the study, delimitation of the scope, and limitations of the study. Chapter two explained the general concept of the proposed green energy production components namely the Photovoltaic, micro-hydro power plant technology, and literature review. Chapter- three explained the potential assessment of the three energy resources in the selected site, primary and secondary data gathering, data analysis, system modeling, and designing the capacity of each component. Chapter four discussed the simulation results of the hybrid components and the Fuzzy logic controller in Matlab/Simulink 2021a. Chapter- five explained conclusions, recommendations, and future works.

CHAPTER TWO

2. THEORETICAL BACKGROUND AND LITERATURE REVIEW

2.1 Theoretical Background of the Study

Renewable energy is energy generated from natural resources such as sunlight, wind, rain, waves and geothermal heat. Renewable is an optional to fossil fuels and was commonly so-called alternative energy in the 1970s and 1980s (R.K.Behl, 2013). A Renewable energy system converts the energy found in sunlight, wind, falling water (rain), sea, waves, geothermal heat, or biomass into a form, we can use such as heat or electricity. Most renewable energy comes either indirectly or directly from the sun and wind and can never be exhausted, therefore they are called renewable and in this research paper, the combination of two renewable energy resources namely solar and Micro-hydro technologies are discussed in detail (Book, Bureau of Energy Efficiency, Application of Non-Conventional and Renewable , 2015).

2.2 Components of Hybrid Energy Sources

Hybrid energy systems combine two or more renewable energy sources to provide a more reliable and cost-effective energy supply. The most common hybrid energy systems include a combination of solar, wind, hydro, and biomass energy sources. In this research mini-hydro, solar, convertors, Energy storage, and diesel generators as the backup have been for the formation of a hybrid power system for the rural electrification under consideration. Electrical energy requirements for rural communities are slightly large and it may not be cost-effective or not be enough renewable energy to implement a stand-alone PV system, micro-hydropower, or any other power source. In this case, it is recommended to combine different types of available power sources to form what is known as a "hybrid power" system. For example, small hydro turbines, solar, and wind can be combined with other power sources such as a power grid or diesel generator to provide enough electrical energy for a city or rural village.

2.2.1 Micro-hydro Power Plant and Its Basic Components

A micro-hydro power plant is a type of renewable energy system that converts the energy of flowing water into electrical energy. Micro-hydro power plants are used in rural areas where access to the electricity grid is limited. The basic components of micro-hydro power plant are:-

i. **Water intake**: The water intake is the point at which water is diverted from a river or stream into the power plant. The intake may consist of a concrete or steel weir or a pipe connected to a dam or reservoir.

ii. **Headrace canal**: The headrace canal is a channel that carries water from the intake to the power plant. The channel is typically lined with concrete or steel to prevent erosion and provide a smooth flow of water.

iii. **Forebay**: The forebay is a small reservoir that collects water from the headrace canal before it enters the turbine. The forebay serves as a buffer to smooth out any fluctuations in water flow and pressure.

iv. **Penstock**: The penstock is a pipeline that carries water from the forebay to the turbine. The penstock is typically made of steel or concrete and is designed to withstand the high pressure and velocity of the water.

v. **Turbine:** The turbine is the component that converts the kinetic energy of the flowing water into mechanical energy. The most common types of turbines used in micro-hydro power plants are Pelton, Turgo, and Francis turbines, depending on the head and flow rate of the water.

vi. **Generator**: The generator is the component that converts the mechanical energy from the turbine into electrical energy. The generator is typically a synchronous generator or an induction generator, depending on the size and capacity of the power plant.

vii. **Control system**: The control system regulates and monitors the operation of the micro-hydro power plant. The system includes sensors, controllers, and software that optimize the performance of the turbine and generator and ensure the safety and efficiency of the power plant.

viii. **Power distribution system**: The power distribution system carries the electrical energy produced by the generator to the end users. The system includes transformers, switchgear, and power lines that connect the micro-hydro power plant to the local electrical grid or to the end users.

The size and capacity of a micro-hydro power plant can vary depending on the available water flow rate and head, and the energy demand of the local community. Micro-hydro power plants can be designed to generate electricity ranging from a few kilowatts to several hundred kilowatts and can provide reliable and cost-effective electricity to rural communities. It is a non-polluting, environmentally friendly source of energy and an exciting prospect to offerElectricity to remote rural communities. Hydropower was established with simple concepts. Water movement rotates a turbine, which is mechanically connected to a generator, andelectricity is produced. Many other elements are needed, but it all starts with the power of water. The use of water falling through a height has been utilized as a source of energy fora very long time (Roger A. Messenger, Photovoltaic Systems Engineering, 3rd ed. New York: CRCPress , 2010.).

A mini-hydropower system is a small system in the range of 10-500 KW. Site-specific conditions that include seasonal variation in water flow, determine the technical feasibility of a given micro- hydro scheme. As a result, detailed hydrological studies must carry out at the site before a potential project proceeds. The simplest micro-hydropower plant is based on a run-of-river design, which means there is no water storage capability. It produces power only when water is running or it might have a relatively small water storage capability. The power generated from water depends on the combination of head and flow. Effective head and discharge rate must be available to produce electricity. Water is dropped from the stream to a penstock/pipeline, where it is directed downhill through a turbine (flow) or turbine to turn it. The vertical drop or gross head creates pressure at the bottom end of the pipeline. The pressurized water developing from the end of the pipe creates the force that drives the turbine. The turbine, in turn, drives a generator that produces electricity. More current or more head generates more electricity.

2.2.1.1 Classification of Mini-Hydropower

Micro-Hydropower Plants can be classified based on the type of Operational feature, the demand for Electrical power, installed capacity, available head at the inlet, the flow rate through the vanes, and specific speed.

2.2.1.2 Classification of Hydropower Based on Operation Feature

It is important to understand the different types of Hydro power plant development.

Run-of-river developments: A dam with a short penstock (supply pipe) directs the water to the turbines, using the natural flow of the river with very little alteration to the terrain stream channel at the site and little impoundment of the water.

Diversion and canal developments: The water is diverted from the natural channel into a canal or a leg penstock, thus changing the flow of the water in the stream for a considerable distance. Pumped Storage Developments. Water is pumped from a lower reservoir to a higher reservoir using inexpensive dump power during periods of low energy demand. The water is then run down through the turbines to produce power to meet peak demand (Roger A. Messenger, Photovoltaic Systems Engineering, 3rd ed. New York: CRCPress , 2010.). Storage regulation developments. An extensive impoundment at the power plant or at reservoirs upstream of the power plant permits changing the flow of the river by storing water during high-flow periods to augment the water available during the low-flow periods, supplying the demand for energy in a more efficient manner. The word storage is used for long-time impounding of water to meet the seasonal fluctuation in water, availability, and the fluctuations in energy demand. While the word poundage refers to the short time (daily) impounding of water to meet the short-time changes in energy demand.

2.2.1.3 Classification of Hydropower Based on the Demand for Electrical power.

Based-load developments: When the energy from a hydropower plant is used to meet all or part of the sustained and essentially constant portion of the electrical load or firm power requirements, it is called a base-load plant. The energy available essentially at all times is referred to as firm power.

Peak-load developments: Peak demands for electric power occur daily, weekly, and seasonally, plants in which the electrical production capacity is relatively high and the volume of water discharged through the units can be changed readily are used to meet peak demands. Storage or poundage of the water supply is necessary (Roger A. Messenger, Photovoltaic Systems Engineering, 3rd ed. New York: CRCPress , 2010.).

2.2.1.4 Classification of Hydropower by Installed Capacity

Hydropower plants can be classified as large, medium, and small, depending on the capacity of energy that can potentially be generated. Plants above 500 MW are generally considered large. Plants between 500MW and 10MW are considered medium-sized. Below 10 MW they are considered small-sized hydro plants. Small hydro plants are further classified as mini (500 kW to 10 MW) micro (10 kW to 500 kW) and Pico (less than 10 kW).

Classification of Hydropower based on Head: The hydraulic head is a key site-specific factor affecting the turbine type selection, equipment, and construction costs of small hydropower. Therefore, representative reference models should be developed for different head ranges and associated turbine types.

i. Low head (2-25m): axial flow (AF) Kaplan/propeller, cross-flow, Francis
ii. Medium head (25-70m): conventional Kaplan/propeller, Francis
iii. High head (>70 m): Francis, Turgo, Pelton

The suggested water head lines are not rigid and are only a means of identifying locations and the choice of turbine depends on the flow rate, and the turbine selection also depends on flow ranges and other factors at the individual sites (Book, Installing photovoltaic systems A Question and Answer Guide for Solar Electric Systems., 1998). The principal components of a simplified Micro Hydropower System is shown below in Fig 2.1. A technical design of the MHP consists of three different engineering aspects (0. Gang Liu, 2012) It includes civil, mechanical and electrical parts. The Civil Components like Intake, Weir, settlingbasin, Headrace, fore bay, Penstock, Powerhouse building, Tailrace, Stop-logs and Reservoir. The Mechanical Components are Trash rack, Penstock pipe Expansion joints, Valves, Turbines,Drive system and Water governor. Finally the Electrical components are Generator, Automatic Voltage Regulator [AVR], Control and Protection System, Earthling System, Transmission Network and distribution networks. Some studies include mechanical and electrical components as powerhouse components. Some components are again elaborated in the following sections.

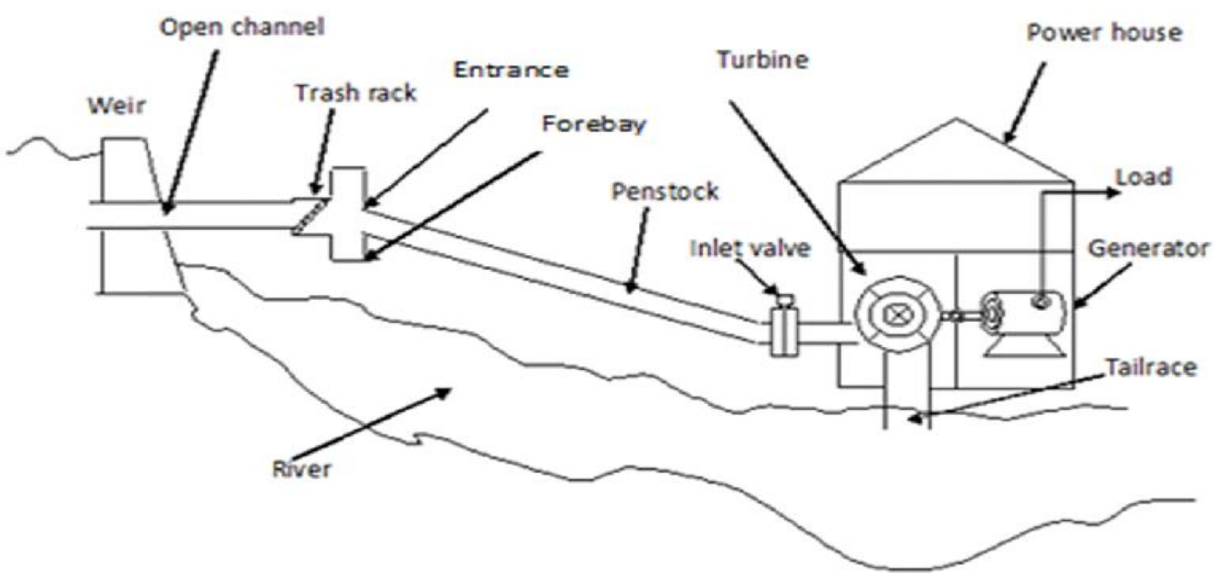


Figure 2. 1 General Layouts of Mini-Hydro System and its Principal (Gang Liu, 2012)

2.2.1.5 Civil Work Components of Mini/micro-hydro power unit

The civil components those of major components are Intake, Headrace Canal, and Settling Basin, spillway, fore-bay tank, penstock, and Tailrace.

Powerhouse Components: The powerhouse components of Micro-Hydropower are used for the conversion of the mechanical energy of water into electrical energy takes place. A powerhouse consists of electro-mechanical equipment such as turbines, generators, and drive systems.

i. Generators

A generator is the main unit that converts mechanical energy associated with water into electrical energy. Two types of generators (synchronous and asynchronous) can be used. Depending upon the size of a machine, types of loads to be fed, and other energy sources later to be integrated, a generator is to be chosen (Roger A. Messenger, Photovoltaic Systems Engineering, 3rd ed. New York: CRCPress , 2010)

ii. Drive Systems

The main purpose of the drive systems is to transmit the power from turbine to the generators at a stable voltage and frequency at a required direction and required speed. Electrical Load Controllers All Micro Hydropower Systems will have switchgear in order to separate the power flow when necessary and to control the electrical power flow. There are several different kinds of switches used in Micro Hydropower System such as isolators, which are manually operated, switch fuses which additionally can provide fuse for current limiting, MCCB (Molded Case Circuit Breakers) which are used for protection from over current or short circuits and also on (Koutroulis, 2006).

Mini-Hydropower Turbines: Energy stored in water will transfer to mechanical energy, which is needed to rotate the shaft of an electric generator. Generally, there are three different types of turbines: impulse, reaction, and waterwheel turbines. The selection of turbine type should be based on the cost-effectiveness and the technical limitations as explained below

i. If the net head (H-net) exceeds 50 m, a cross-flow turbine is not a preferred option, especially for the output power below 20 kW. As a rule, a runner’s width should not be less than 15 to 20% of the diameter otherwise, it causes a decrement in efficiency. The power available from all types of turbines can beexpressed as follows

$$P_e = Q \eta_t \, g \, \eta_g \, H_{net} \quad (2.1)$$

Where- Pe -Nominal electric power (W). ɳt-the efficiency of turbine, ɳg-Efficiency of generator, Q-Design flow rate m3 /s, g-Acceleration due to gravity m/s2 and H-net-Net Head m.

ii. The efficiencies at the rated output to be used in a feasibility study are as follows: -Pelton 5-30 kW: 70-80% - Pelton above 30 kW: 75-85% - Cross- flow 5-30kw: 60-70%- Cross-flow above 30 kW: 65-78%

2.2.2 Solar Energy and Photovoltaic Technology

The solar cell is the elementary building block of photovoltaic technology. Solar cells are made of semiconductor materials, such as silicon. One of the properties of semiconductors that makes them most useful is that their conductivity may easily be modified by introducing impurities into their crystal lattice. There are several types of solar cells. However, more than 90% of the solar cells currently made worldwide consist of wafer-based silicon cells. They are either cut from a single crystal rod or from a block composed of many crystals and are correspondingly called mono-crystalline or multi-crystalline silicon solar cells. Wafer-based silicon solar cells are approximately 200µm thick. Another important family of solar cells is based on thin films, which are approximately 12 µm thick and therefore require significantly less active semiconducting material. Thin-film solar cells can be manufactured at lower cost in large production quantities; hence their market share will likely increase in the future. However, they indicate lower efficiencies than wafer-based silicon solar cells, which means that more exposure surfaces and materials for the installation are required for a similar performance (Ashok, 'Optimized model for community-based hybrid energy system', Renewable Energy 32 (7), pp. 1155-64, 2007).

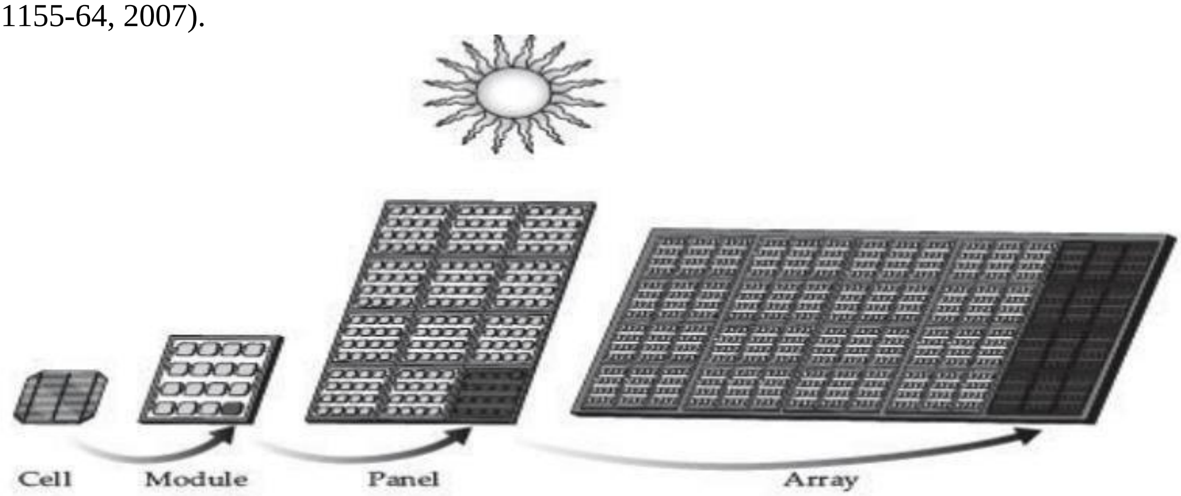


Figure 2. 2 PV system Component (Ashok, 2007)

2.2.3.1 Common Terminologies of Photovoltaic Cells

Solar irradiance: is an instantaneous quantity describing the rate, or flux of solar radiation (power) incident on a surface, commonly expressed in units of kilowatts per square meter (KW/m2) and Solar insolation: is an amount of solar energy received on a surface commonly expressed in units of kilowatt-hours per square meter (kWh/m2) (N. Argaw, 2001)

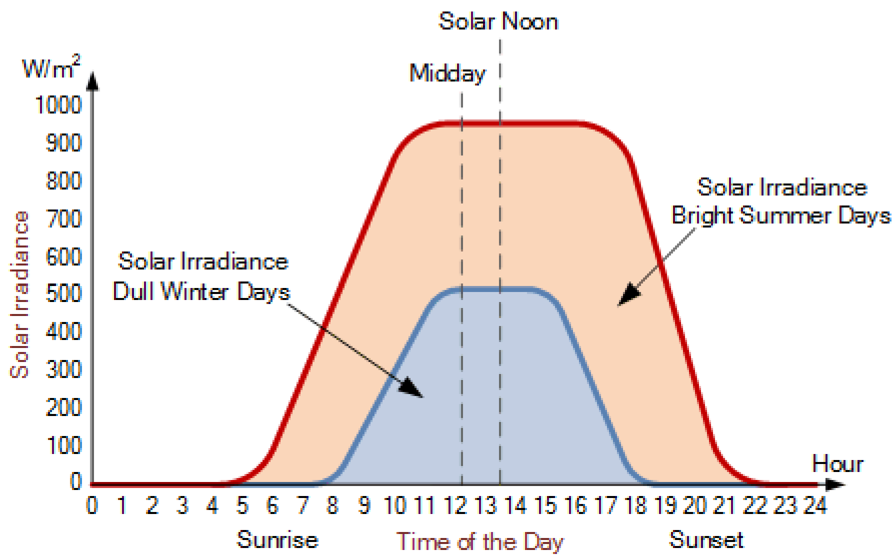


Figure 2. 3 Relation between solar irradiance and solar insolation (Ishaq M., 2013)

Photovoltaic rating: Photovoltaic modules are available in a range of sizes. Those used in grid-tied or stand-alone systems range from 80W to 300W. The performance of PV modules and arrays is generally rated according to their maximum DC power output (watts) under the Standard Test Conditions (STC). Standard Test Conditions are defined by a module (cell) operating temperature of 25^{o} C(77^{o}F), an incident solar irradiant level of 1000W/m2, and under Air Mass of 1.5 spectral distribution. Since these conditions are not always present PV modules and arrays operate witha performance of 85 to 90 percent of the STC rating.

Photovoltaic Technology. Many crystalline or thin-film PV modules power a solar PV system. Individual PV cells are interconnected to form a PV module. The “family tree” in figure 2.4 gives an overview of thesetechnologies available today and figure 2.5 illustrates some of these technologies.

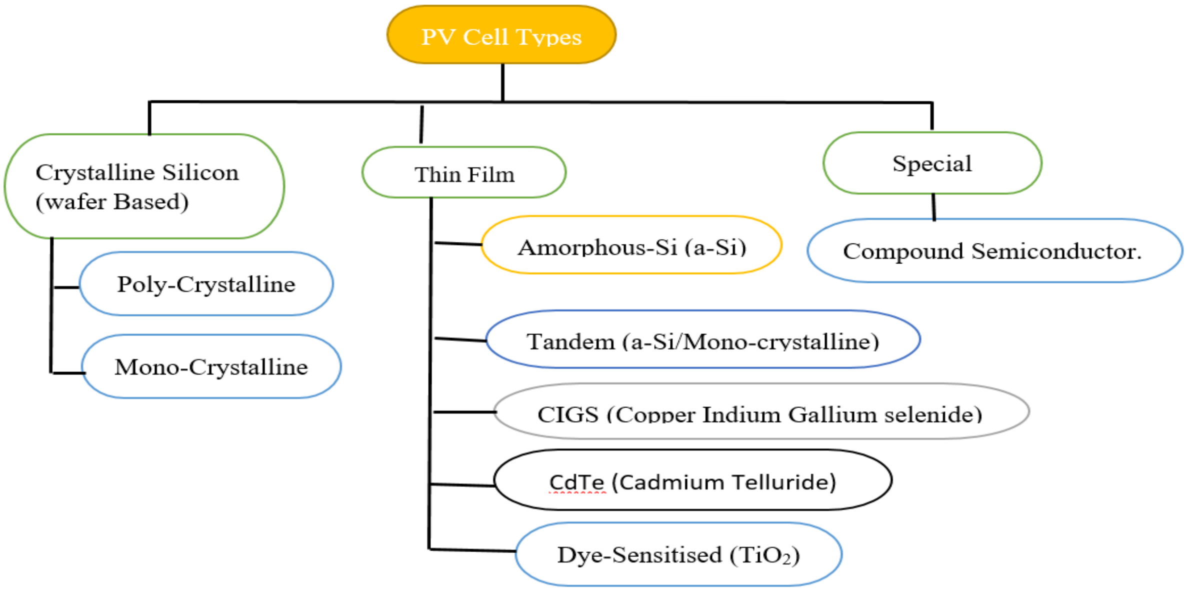


Figure 2. 4 PV Technology family trees (John, 2001)

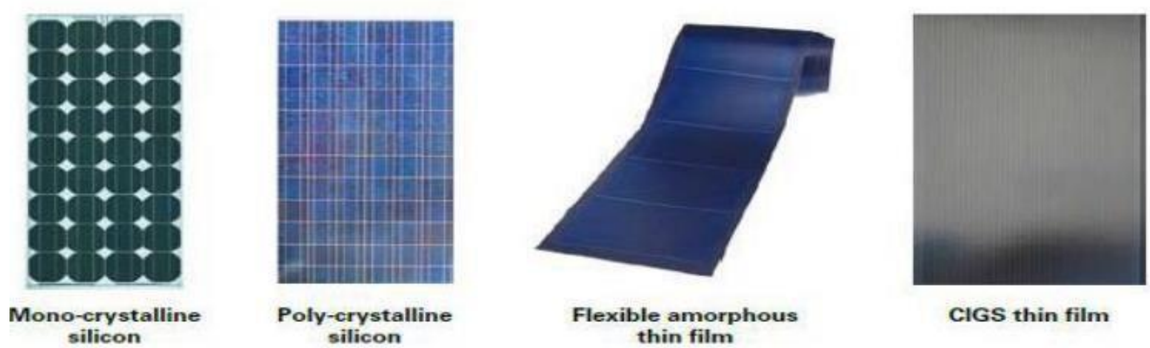


Figure 2. 5 Common PV module Technologies (John, 2001)

Table 2. 1 Technology and Module Efficiency of PV (John, 2001)

Technology	**Module Efficiency**
Mono-Crystalline Silicon	12.5-15%
Poly-Crystalline Silicon	11-14%
Copper indium Gallium Selenide (GIGS)	10-13%
Cadmium Telluride (CDTE)	9-12%
Amorphous Silicon(a-Si	5-7%

2.2.3.2 Electrical Characteristics of the Solar

The complex physics of the PV cell can be represented by the equivalent electrical circuit shown in figure 2.6 below. The following parameters called for consideration. The current/at the output terminals is equal to the light-generated current Iph (less the diode Id) and the shunt-leakage current Ish/. The series resistance Rs represents the internal resistance to the current flow, and depends on the p-n junction depth, impurities and contact resistance. The shunt resistance Rsh is inversely related to the leakage current to the ground. In an ideal PV cell Rs=0 and Rsh= the PV conversion efficiency is sensitive to small variations in Rs, but insensitive to variations in Rsh. A small increase in Rs can decrease the PV output significantly.

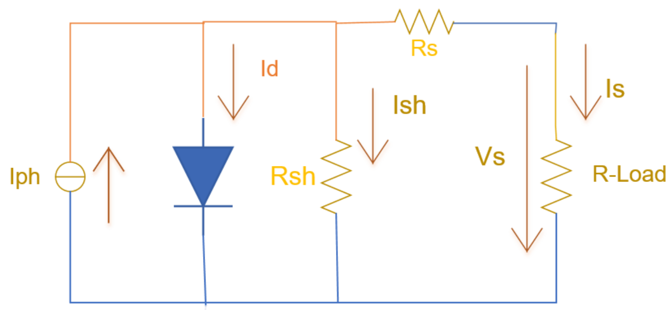


Figure 2. 6 Equivalent Circuit for PV Cell (John, 2001)

P-V Curves of Photovoltaic Cells: Current-voltage relationships are used to measure the electrical characteristics of PV devices and are depicted by curves. The current-voltage, or I-V, curve plots current versus the voltage from short-circuit current Isc through loading to open circuit voltage Voc. The curves are used to obtain performance levels of PV systems (cells, modules, arrays) [Solar energy, renewable energy, and the environment] (John, 2001). Each I-V curve has a set of distinctive operation points that should be understood in order to appropriately install and troubleshoot PV power systems:

- Short-circuit current (Isc) is the maximum current generated by a cell or module and is measured when an external circuit with no resistance is connected (i.e., the cell is shorted).
- Maximum power operating current (IMP) is the maximum current specified in Amperes and generated by a cell or module corresponding to the maximum power point on the array's current-voltage (I-V) curve.
- Open-circuit voltage (Voc) is the maximum voltage generated by the cell. This voltage is measured when no external circuit is connected to the cell.

- Rated maximum power voltage (VMP): corresponds to the maximum power point on the array's current-voltage (I-V) curve.
- Maximum power (PMP) is the maximum power available from a PV cell or module and occurs at the maximum power point on the I-V curve. It is the product of the PV current (IMP) and voltage (VMP) (Book E. 2., 2000).

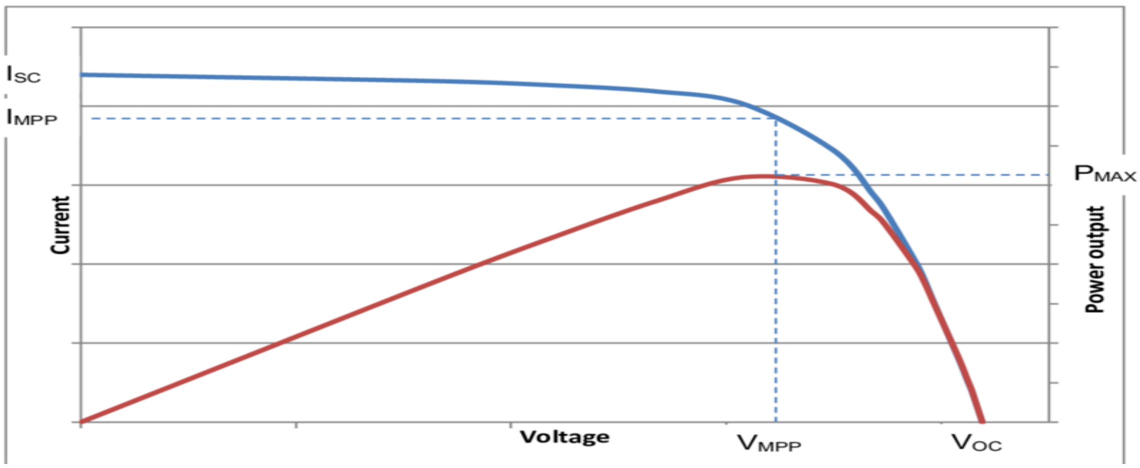


Figure 2. 7Typical I-V and Power Curves for a Crystalline PV module operating at, 1000W/m2 (STC) (Book E. 2, 2000)2.2.3.3 Solar system interconnection

In order to obtain high currents and voltage (reaching up to kilovolts), PV cells are connected in series-parallel. Usually, PV cells inside the PV module are manufactured with very similar characteristics to avoid the circulation of internal currents among the cells. Therefore, it can be assumed that the PV cells are identical when they are connected in series or parallel. Connecting PV cells in series results in an increase in the voltage across PV panels, whereas connecting PV cells in parallel, results in an increase in the output current from PV panels (Book E. 2., 2000). Type of Wire and Size: The performance and reliability of a PV system are increased if the correctsize and type of wire are chosen. Switches and Fuses: Fuses are used in PV systems to provide over-current protection when ground faults occur and switches are used to manually interrupt power in case of emergency or maintenanceand Connections.

2.2.3 Diesel Generator

The generator runs on a variety of fuels, including gasoline, diesel, propane, and biofuel. Compare to renewable energy installations, generators have low capital costs and produced power on demand.Disadvantage of generator operation include fuel dependence, transport and storage costs, high maintenance cost and exposure to noise and pollution. Diesel generators are most commongenerators in a large number of small and remote power systems throughout the world.

2.2.4 Maximum Power-Point Tracking

The maximum power (MP) is obtained when the solar panel is being operated at the voltage wherethe global maximum of the P-V characteristic lies. It shows that for one specific operating point, themaximum power output can be obtained from the solar panel. Therefore, the efficiency of the algorithm is very important.

2.2.5 Energy Storage system (Battery)

The electrical energy is stored in the batteries in order to be provided in intervals with minimum solar irradiance (during nights, and cloudy days). Solar energy systems for this deep-cycle lead-aciddeep-cycle battery. This type of battery is different from a conventional car battery, as it is designedto be more tolerant of the somewhat ongoing charging and discharging would expect when variablesunshine from one day to the next has deep-cycle-acid deep-cycle batteries last longer but it also costmore than a conventional battery. The plate is made of a sponge-like material (Penick, December 4, 1998).

2.2.6 Power Electronic Converter

A converter is a device that converts electric power from dc to ac in a process called inversion, fromac to dc in a process called rectification or both. It has an inverter and a rectifier to do the conversions from DC to AC and an inverter for AC to DC.

2.3 The Application of HOMER Software

HOMER is a micro-power optimization-modeling tool, which was developed by the National Renewable Energy Laboratory (NREL) of the United States Department of Energy (DOE) for the Village Power program. The software tool has the ability to determine the system structure, system components and size, cost and resource availability and many technological options. Its main advantage over other hybrid energy system design software is that it can simplify complex hybrid energy design and make informed decisions in difficult situations. HOMER simulated the operation of the system by making energy balance calculations for each of the 8,760 hours in a year. For each hour, HOMER calculates energy flows to and from each component of the system by comparing the hourly electrical and thermal energy demand with the energy the system can supply during that hour. For systems that include batteries or fuel-powered generators, HOMER is used every hour to determine how to operate the generators and charge or discharge the batteries. For each system configuration under consideration, HOMER performs these power balance calculations and determines whether that configuration is feasible. (Ayodele T. R., Mathematical methods and software tools for designing and economic analysis of hybrid energy system. International Journal ofRenewable Energy, 9(1), 57-68., 2014). This means it checks whether the proposed system meet the electric demand under the given conditions, and it estimates cost of installing and operating the system over the lifetime of the project. System cost calculations include capital, replacement, operation and maintenance, fuel, and interest costs. System cost calculations include costs such as capital, replacement, operation and maintenance, fuel and interest. The software has the ability to perform system optimization. HOMER performs three main functions: simulation, optimization and sensitivity analysis based on the raw data provided. Figure 2.8 shows how simulation, optimization and sensitivity analysis are interrelated. The oval figure enclosed in another oval figure shows that one optimization consists of multiple simulation and one sensitivity analysis consists of multiple optimizations (Ayodele T. R., 2014).

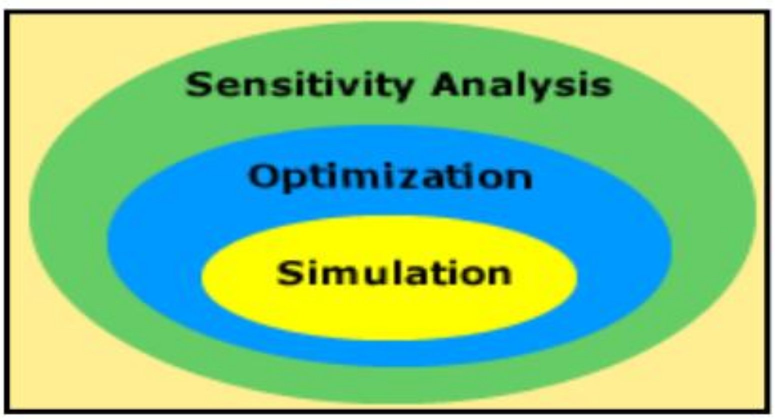


Figure 2. 8 Interactions between simulation, optimization and sensitivity analysis (Homer, 2016)

Simulation: Compares the power supply and load demand from the system at 1 hour and 8,760 hours. During this time it decides either to use load following or dispatch strategy to

Operate batteries and generator. For a system, that contains battery and generator requires having dispatch strategy. Dispatch strategies are two types, load following and cycle charging strategies.

Optimization: In this process, it simulates each of the different system configurations to find the lowest NPC and lists each of the power systems that meet the load demand.. The purpose of optimization is to determine the best system based on the decision variables set by the designer. A decision variable is a variable that is controlled by the designer. HOMERs decision variables such as; PV array size, head and water flow, generator size, inverter size, number of batteries, delivery strategy.

Sensitivity analysis: It examines the effect of external parameters and makes adjustments for each sensitivity variable. First defining the variables that can affect the system over its entire life is mandatory to input into the software. After specifying the sensitive parametric variables as input in the software, the optimization process is repeated. The sensitivity variables can be climatic data.

The parallel configuration, current hybrid energy system, software simulations and designs are based on this model design as shown in figure 2.9

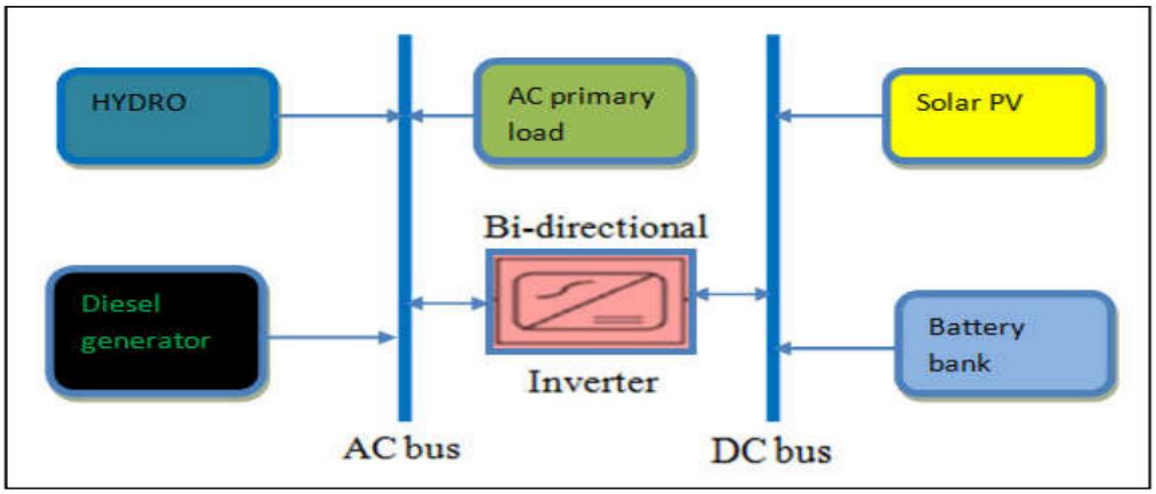


Figure 2. 9 Hybrid system Configuration in Homer Microgrid Technology

A microgrid is a localized group of electricity sources and loads that normally operates connected to and synchronous with the traditional centralized grid, but can also disconnect and function autonomously as physical and/or economic conditions dictate. Microgrid technology is a rapidly developing field that aims to provide a more reliable, resilient, and cost-effective energy supply by integrating renewable energy sources, energy storage systems, and advanced control systems. The basic components of a microgrid include:

i. Distributed energy resources (DERs): DERs are the sources of electricity that are integrated into the microgrid. They can include renewable energy sources such as solar PV, wind turbines, and micro-hydro power plants, as well as conventional fossil fuel generators

ii. Energy storage systems (ESSs): ESSs are used to store excess energy produced by the DERs for use during periods of low energy production. Common ESSs used in micro-grids include batteries, flywheels, and pumped hydro storage.

iii. Power electronics and control systems: Power electronics and control systems are used to regulate and monitor the operation of the DERs and ESSs in the microgrid. They can include inverters, converters, and controllers that ensure the quality and reliability of the electrical power

iv. Communications and monitoring systems: Communications and monitoring systems are used to monitor and control the operation of the microgrid. They can include sensors, software, and communication networks that enable real-time monitoring and control of the microgrid components

v. Load management systems: Load management systems are used to manage the energy demand of the end users in the microgrid. They can include demand response programs, energy efficiency measures, and load shedding strategies that help to balance the energy supply and demand in the microgrid.

vi. Islanding protection systems: Islanding protection systems are used to ensure the safety and reliability of the microgrid in the event of a grid outage. They can include relays and switches that prevent the microgrid from feeding power back into the grid and protect the microgrid components from damage. Microgrid technology offers several advantages over traditional centralized power systems, including:

    a) Improved reliability and resilience: Micro-grids can operate autonomously and continue to provide power during grid outages or other disruptions.

    b) Cost-effectiveness: Micro-grids can often provide power at a lower cost than traditional centralized power systems, especially in remote or rural areas where grid extension is expensive.

    c) Increased use of renewable energy: Micro-grids can integrate a variety of renewable energy sources to provide a more sustainable and environmentally friendly energy supply.

    d) Improved energy efficiency: Micro-grids can employ load management systems and other energy efficiency measures to minimize energy waste and improve overall energy efficiency.

Microgrid technology is being increasingly adopted around the world, especially in areas with unreliable or limited access to the electricity grid. The continued development and improvement of microgrid technology is expected to play an important role in the transition to a more sustainable and resilient energy system.

2.4 Literature Review/Related Works/

Here is some literature on the feasibility study and optimal design of hybrid renewable energy microgrid systems for rural electrification, along with their publication dates:

I. **Published in Renewable Energy**, 2017, Feasibility study of a hybrid renewable energy microgrid system for a rural community in India. The study mainly deal that feasibility study of hybrid renewable energy in order to build the microgrid system.

II. **Sani Salisu**, 2019 Techno-Economic Feasibility Analysis of an Off-Grid Hybrid Energy System for Rural Electrification in Nigeria. The study was mainly focused on economic feasibility of off-grid hybrid energy system.

III. **Renewable and Sustainable Energy Reviews**, 2020. "Design and implementation of a hybrid renewable energy microgrid system for a remote mountainous community in Vietnam,"

IV. **Sustainable Energy Technologies and Assessments**, 2018 "Design and performance evaluation of a solar-wind hybrid microgrid system for a remote island community in Bangladesh," .

V. **Journal of Energy Storage**, 2019 "Assessment of a hybrid microgrid system for a rural community in Tanzania using solar PV and micro-hydro power plants,".

VI. **Thomas Rwahama**, 03 October 2022, Feasibility study of hybrid Hydro-PV power plant possible deployment in remote rural area. He is mainly focusing the feasibility study of potential renewable energy resources and possible deployment for rural area communities.

VII. F**arshid Mostofi**, 2016 Feasibility and Optimal Reliable Design of Renewable hybrid energysystem for rural Electrification in, which focused on Feasibility study was done,the resources are Optimized Using HOMER PRO software and Hybrid system designed.

VIII. **J.P. Sharma**, Oct, 2015, (J.P.Sharma, 2015), this paper investigates the feasibility of a stand-alone hybrid energy system to meet out electric load requirements of JK Lakshmipat University, Jaipur. In addition, to maintain a continuity of electricity supply, a single energy source is not a good option. Therefore, it is considered a hybrid system with a wind turbine, solar Photovoltaic and diesel generator with integration a of battery bank. The techno-economic analysis for the proposed hybrid system model has been performed using HOMER software. But variation of the load for month and a yearare considered as only 10% and 20% respectively and intelligence decision making software is not used for load and supply power variations.

IX. Lovisa Bergman and Amanda Enocksson, 2015 (bookk), this paper proposed a renewablepower generation system for Addis Ababa Institute of Technology (AAiT). The aim of hybridizing renewable energy sources is that the main load shall be covered by the available solar energy source and other sources shall function as a complement when there is a deficiency in the main resource. Four backups to the PV system are examinedto find the optimal solution: battery, diesel generator, and the two hybrid systems with battery or diesel generator or grid, and the configurations made to find the optimized system were modelled in HOMER software. Nevertheless, in this paper, it is not proposed any intelligent decision-making software for load or supply energy capacity variation.

CHAPTER THREE

3. METHODS AND MATERIALS

3.1 Introduction

There is no access to electricity in the Kola-Kinibibit kebele, however, based on the data collected, and data analyzed there were huge renewable resources such as solar and hydropower resources that can generate renewable energy. Renewable energy technology can play a key role in electricity generation, as grid expansion is not cost-effective. This study focused on the techno-economic feasibility and optimal design of a hybrid Power system to electrify a typical Kola-Kinibibit kebele village in southwest Ethiopia. It aimed to achieve electrification at minimal cost while considering the constraints of environmental pollutant emission. This study determined the technical details and the economic feasibility of setting up such a power system using the hybrid optimization of multiple energy resources (HOMER) simulation tool. Different combinations of energy resources were compared and analyzed. The system performance and economics use some determinant factors such as the cost of energy, operation, and maintenance cost, net present cost, excess electricity, capacity shortage, generator fuel consumption rates, load fulfillment, and CO_2 and other pollutant gas emission savings were determined. Finally, Modeling and simulation of the entire optimal hybrid power system were demonstrated using MATLAB/Simulink software including microgrid power system control and operation time.

3.2 Description of the Study Area

The study was conducted in Jimma Zone - Gera wereda - Kola - Kinibibit Kebele in Southwest Ethiopia, which is located at latitude 7.707269° N and longitude 36.414828° E and is about 100 km far from Agaro town. The Kebele has a population of 2890 currently (2022 G.C), of which 1344 are men and 1546 are women, 405 households, a primary school, a church, a mosque, 4 grocers, 4 shops, 3 barbershops, 3 female salons, a small-scale rural industry, and a small agricultural irrigation system place. The majority of income-generating activities in this village are agriculture, and livestock keeping, at present, villagers use kerosene lamps, disposable batteries, rechargeable batteries, candles, small single-phase diesel generators, and a few small solar house systems for lighting. A few of these energy sources are sometimes used as power sources for entertainment and communication. Traditional biomass such as firewood is used as a fuel for cooking according to the village administrative chairperson said. In order to generate the hydropower plant, Naso Rive was proposed, located near the village about 40 km away.

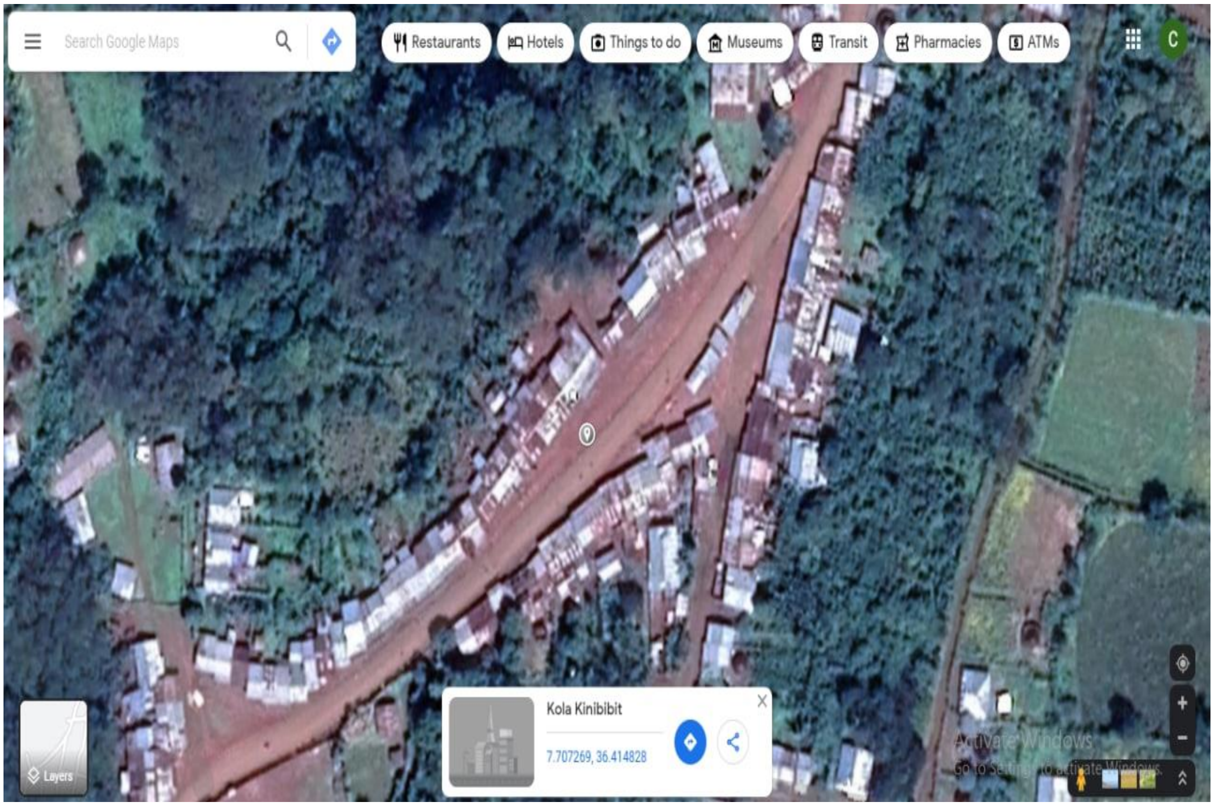


Figure 3. 1 Google map of Kola-Kinibibit kebele

3.3 Data Collection

Primary and secondary data were collected to demonstrate the study. Primary data was collected directly from the site, which is the electricity demand of the village, and hydropower plant required resources whereas secondary data was collected from related literature, the National Aeronautics and Space Administration (NASA) and The Ministry of Water and Energy of Ethiopia (MoWE).

3.3.1. Primary Data Collection

The village's electricity demand was collected by interviewing the head of the school, religious leaders, village administration chairperson, head of the health center, and village residents. The gross head conducted a field survey using a mobile GPS at a selected Naso River area and flow rate (Discharge) data was collected from the Ethiopian Ministry of Water and Energy data. All Collected primary data is shown in Table 3.1.

Table 3. 1 Details of the survey conducted to collect primary data.

Necessary data collected	**Value**	**Sources**
Number of Households (2022 G.C)	405	From Village Administration Chairperson
Design flow rate	150l/s	From The Ministry of Water and Energy of Ethiopia
Gross head of the Naso River	60m	By using the Portable GPS Tool
Number of groceries	4	By interviewing the villager residents
Number of shops	4	By interviewing the villager residents
Number of female salons	3	By interviewing the villager residents
Number of Barbershop(Male)	3	By interviewing the villager residents
Number of Bar	2	By interviewing the villager residents
Number of religious houses	2	By interviewing the religious leaders
Number of health post	1	By interviewing the head of Health Post
Number of primary schools	1	Interviewing the head of the School
Village administration office	1	By interviewing Village Administration Chairperson
Small-workshop	1	By interviewing Village Administration Chairperson
Small-agricultural irrigation center	1	By interviewing Village Administration Chairperson

3.3.2. Secondary Data Collection

Secondary data is the cost of hybrid power units, the value of temperature in the village per month, and the solar radiation, which are obtained from other related articles, the website, and the National Aeronautics and Space Administration respectively. The capital cost of equipment is taken from the website and adjusted to the local value by including transportation and other costs. Therefore, the cost of hybrid energy components is estimated accordingly.

Table 3. 2 Secondary data collected from various sources

Necessary data collected	**Description**	**Sources**
Solar Radiation	Solar radiation was collected from NASA	National Aeronautic and Space Administration(NASA 2021 G.C)
Village temperature value	Kola-Kinibibit kebele Temperature was collected from NASA	National Aeronautic and Space Administration(NASA 2021 G.C)
The number of households in 2021 G.C is 339	Previous Number of Household needed to predict future population growth	The data was received from the Village administration chairperson’s office
Hybrid Power Component Cost and Type	Battery storage, PV module, Diesel generator, and Converter	Related literature and websites

3.4 Data Analysis

The electricity load demand of the village, Micro-hydro-power plant resources, Solar PV power plant resources, Hybrid Power components cost, and other related resources assessment analysis have been discussed as follows-

3.4.1 Village Load Assessments

Village electricity load demand has been assessed based on residential (domestic), Commercial, Public (Community), municipal, and Small –scale industry primary loads. It can be calculated the Energy demand (kWh) = (number of appliances used × power rating of each appliance (W) × hours of operation (hr) × no of days per week)/1000).

3.4.1.1 Households Load Demand Analysis

Household Load is estimated based on the population of the area, the number of houses in that area, the number of appliances used, and the hourly consumption patterns of the appliances. It assumed that high-income households are 20% of the total population of the village and low-energy income households are about 80% of the total population of the village. Domestic appliances for kola-Kinibibit kebele communities are used for lighting, entertainment, and communication. Appliances such as LED light tubes (energy saver lamps), TV sets, radio sets, mobile phone chargers, cooking stoves (Single), and The conventional electric “Enjera” baking machine consumes an average power of 12kW/m2 of pan surface area and the effective pan diameter is about 55 cm (A., 2011).

It assumed that a Cooking stove, electric mitad, and a TV were suggested for high-level households, and a small-scale house for the rural community was assumed that had a four-roomed family house one for the parents and the other two for children that are girls and boys the fourth one for a sitting room.

Table 3. 3 Household electric consumption features (high-income household)

Appliances	Quantity	Wattages (W)	Hours of Use	Working time	20% of Total HH Load (kW)	Energy (kWh/ d)
LED Tube Lamps	5	9	6	18:00-00:00	3.645	21.870
LED 32-Inch TV	1	41	4	18:00-22:00	3.321	13.284
Radio working days	1	30	6	18:00-00:00	2.430	14.580
Cooking stove ((one sit stove)	1	1000	4	06:00-08:00 &17:00-19:00	81.00	324.000
Enjera Mitad	1	2850	2	17:00-19:00	65.957	131.914
Mobile charge	1	15	3	06:00-08:00 20:00-21:00	1.215	3.645
Grand Total					157.567	509.293

Table 3. 4 Household Electric Consumption Features (low-income HH)

Appliances	Quantity	Wattages (W)	Hours of Use	Working time	80% of Total HH Load (kW)	Energy (kWh/ d)
LED Tube Lamps	5	9	6	18:00-00:00	14.580	87.480
Radio working days	1	30	6	18:00-00:00	9.720	58.320
Mobile charge	1	15	3	06:00-08:00 20:00-21:00	4.86	14.580
Grand Total					29.16	131.380

The main target for choosing the items in Tables 3.3 and 3.4 are considering the minimum energy saving. Therefore, the village's residential Energy is 640.673 kWh per day. In addition, the maximum load is 186.727 KW/day.

3.4.1.2. Commercial Electric Load

Commercial load refers to the amount of electricity that is consumed by commercial businesses, such as groceries, bars, shops, saloons (female), and Barbershops (male). Commercial Load can vary depending on a number of factors, including the size of the business, the equipment, and the appliances used. Therefore, in this study, there was considered as a small business, and it was estimated as shown in Table 3.5.

Table 3. 5 Commercial electric load

Type of Customer	Number of customers	Wattage per customer(W)	Energy per Customer (Wh)	Total Wattage(KW)	Total Energy(KWh)
Grocery	4	585	5810	2.180	23.240
Local small bar	2	595	6000	1.190	12.000
Female salon	3	250	2270	0.750	6.810
Barbershop	3	185	1440	0.555	4.320
Small shop	4	530	5910	2.120	23.640
Grand Total				**6.795**	**46.37**

The total energy demand for commercial load is 46.37 kWh/day and the peak load is 6.795 KW/day.

3.4.1.3. Community Load Demand

Community consumers included primary schools, churches, mosques, and health posts. A load assessment profile for the individual consumer was established according to the size of the building and the energy requirement of the prospective consumer. The village's primary school contains 8 classrooms, 3 toilet rooms, 1 unit desktop computer, and 1 unit printer. As noticed above during the daytime there is no need for electricity for the classrooms since the sunlight can brighten the classes through the windows. Each of the classrooms is assumed to be installed with 2 units of compact fluorescent lamps, Moreover, 3 units of CFL for the school surroundings lighting is also proposed. During the weekends, evening classes will acquit in the daytime from 8:00 to 12:00. Annual vacation for schools is is during July and August and the semester break is in January. The total daily electricity has consumed by the school except for January, July, and August is shown in Table 3.6. However, the load during the annual school break (during July, August, and the semester break in January) can be compensated by the load consumption during the weekday evening classes. The total energy demand for the School load is 1.757 kWh/day and the peak load is 0.459 KW/day.

Table 3. 6 Primary School electric load demand

Electrical appliances	Quantity	Capacity (W)	Run-time (h/d)	Working time	Load(kW	Energy (kWh/ d)
Classroom light (CFL)	8	15	3	18:00-21:00	0.12	0.36
Toilet room light (CFL)	3	11	3	18:00-21:00	0.033	0.099
External light (CFL)	3	40	3	18:00-21:00	0.12	0.36
Staff room light (CFL)	2	13	3	18:00-21:00	0.026	0.078
Computer	1	150	8	8:00-12:00 13:00-17:00	0.1	0.8
Printer	1	60	1	15:00-16:00	0.06	0.06
Total					**0.459**	**1.757**

The main possible appliances that draw electric power in this clinic are low-energy light bulbs, a TV, a computer, a printer, a water heater, a laboratory microscope, and a vaccine freezer. The health post has 14 rooms including reception and toilet rooms lighted with 13W fluorescent lump and two units of 40W lumps for external lighting.

Table 3. 7 Health Post's Electric Load Demad

Electrical appliances	Quantity	Capacity (W)	Run-time (h/d)	Working time	Load (kW)	Energy (kWh/ d)
Room lighting[CFL	10	13	8	8:00-12:00 13:00-17:00	0.13	1.04
Toilet light(CFL)	2	13	3	18:00-21:00	0.026	0.07
External light(CFL)	2	40	6	18:00-00:00	0.08	0.48
Television	1	70	12	08:00-20:00	0.07	0.84
Computer	1	150	8	8:00-12:00 13:00-17:00	0.1	0.8
Printer	1	50	1	14:00-15:00	0.05	0.05
Lab. Microscope	1	20	4	8:00-12:00	0.02	0.08
Vaccine freezer	1	60	24	24:00:00	0.06	1.44
Water Heater	1	1000	3	8:00-11:00	1	3
Total					**1.536**	**7.8**

The daily energy consumption by the health center is 7.80kwh and with a peak load of 1.536kW

Table 3. 8 Electric Load Demand of Religious

Appliances	Quantity	Wattages (w)	Run time (h)	Working time	Load (Kw)	Energy(KWh)
Megaphone	2	15	5	18:00-20:00 & 9:00 -12:00	0.03	0.15
Hole lighting	4	60	3	18:00-21:00	0.24	0.72
Staff Lighting	4	13	3	18:00-21:00	0.052	0.156
Toilet light	4	11	3	18:00-21:00	0.044	0.132
Printer	1	60	1	11:00-12:00	0.06	0.06
Computer	1	150	3	8:00-11:00	0.15	0.45
Total					**0.576**	**1.668**

The daily energy consumption by the health center is 1.668 kWh and with a peak load of 0.576kW

3.4.1.4 Small-scale Industrial and Municipal Load

Small-scale industrial units in villages can be an important tool for promoting rural development and creating sustainable livelihoods in rural areas. There is a small workshop, which had a small training room that can handle 20 students per training in the village. The workshop is about a single-phase induction motor and fundamental electric laboratory-testing bench. The platform was created by the collaboration of electrical engineering graduates living in the village. In addition, there is a water pumping motor for a coffee plantation in the village so it was taken as Municipal Load as shown in Table 3.9.

Table 3. 9 Small Scale industry, and Municipal load

Load classification	Type of Customer	Number of customers	Wattage per customer (W)	Energy per Customer (Wh)	Total Wattage(kW)	Total Energy(kWh)
Small Industrial Load	Computer class	1	1360	9530	1.360	9.530
	Electrical laboratory	1	12035	14130	12.035	14.130
	Carpentry small workshop	1	2572	7594	2.572	7.594
Municipal Load	Agriculture irrigation center	1	5930	5930	5.930	5.930
Grand Total						37.184

3.4.1.5 A Three-Year Forecast of the Population of the Kola-Kinibibit Kebele

Power and population projection are two important factors that are closely linked to each other. As the population grows, the demand for power also increases, and this can have significant implications for energy planning and policy. Population projection refers to the estimation of future population growth based on current demographic trends and assumptions. Power projection, on the other hand, refers to the estimation of future power demand based on the current energy consumption patterns and assumptions. Ethiopia electric utility Agaro district manager said that the national grid would be extended after three years. Therefore, this study was done with a power and population projection of three years for assumed low-income household energy consumption and commercial load. In 2022, the population is 2890, and in 2021, the population is 2677 according to the Village administration chairperson said with 405 and 339 households s respectively.

$$R = \frac{2890-2677}{2677} * 100\% = 7.96\% \text{ yr.} \quad (3.1)$$

To estimate the number of the population in the coming two years,

$$Pn = Po\,(1+r)^{n} \quad (3.2)$$

Pn= population at time n in the feature Po= present population r=annual growth rate of population n= Year of projection. P2= 2890 $*$ (1 + 7.96/100) ^{3} $\approx$ 3637 population. By using the Excel sheet, the projected power can be calculated with consideration as it is known that there will not be further extensions in school, health post, small scale, and Municipal loads that can accommodate the coming three years load. There Kola Kinibibit village’s daily total energy demand is 987.626 kWh/day. The total yearly energy demand of the village energy demand is estimated as 987.626 kWh x 365= 360,483.49 kWh/year.

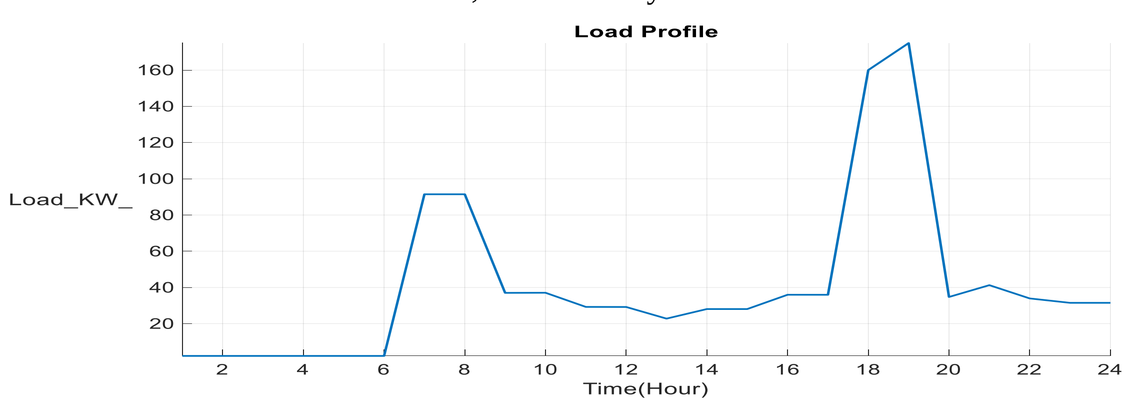


Figure 3. 2 Load demand of Kola-Kinibibit Kebele

3.4.2 Micro Hydro Resource Assessment

This study focused on micro-hydro-electric power plants, which can be generated between 5 and (100) Kilowatt of power when they are installed across rivers and streams. To design a micro-hydro-electric power plant, there are many considerations to be prepared and taken into account in the design procedure. These considerations are

3.4.2.1 Preliminary Study

The preliminary studies could be in the form of pre-feasibility or design studies. A pre-feasibility study generally considers various options and uses estimates. The first requirement for a successful hydro scheme is to find the best possible site where there is a good combination of head and flow rate so that the output is maximized. A series of tasks that may be conducted during the preliminary survey covering technical, economic, social, and environmental aspects are taken into account. Therefore, the Topographic/geological survey and Hydrological survey have been done at the Naso River. The main purpose of the topographic and geological survey has been to assess the best locations for proposed civil works and estimate construction and maintenance costs. Hydrological Survey is used to Compare Catchment Areas, Find the average daily flow (ADF), identify the Absence of local rainfall data, and know the Seasonal flow variation. Therefore, the hydropower plant site was selected based on head availability, availability of water, topography, or geographical and local environment as it is shown in Figure 3.2.

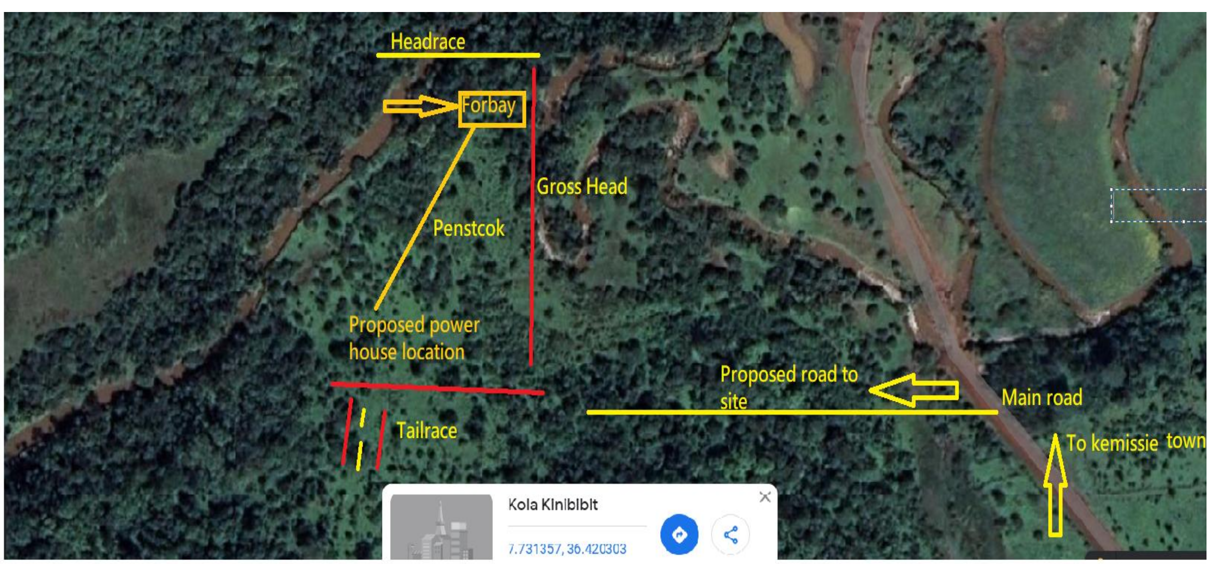


Figure 3. 3 Proposed Naso River MHP the site

3.4.2.2 Head Measurements

The total (or gross) head available is one of the most important details required from a site survey or direct measurement at the selected site. Gross head (Hg) is the head between the inlet and the tail of the water surface for reaction turbines (such as Francis and Kaplan turbines) and induced turbines (such as Pelton, Turgo, and cross-flow turbines). The modern electronic digital levels provide an automatic display of height and distance in about (4) seconds with a measurement accuracy of (0.4 mm). Surveying by Global Positioning Systems (GPS) is already practiced and a handheld GPS receiver is ideal for field positioning and rough mapping, based on this gross head of the selected hydropower plant is 60m. Once the total head is known, the net head (Hn) can be calculated by subtracting the losses in the path, such as open channel losses, waste losses, losses to or entering the penstock, gate or valve losses, and penstock friction loss. Figure 3.3 is shown a head loss, gross head, and net head differentiation.

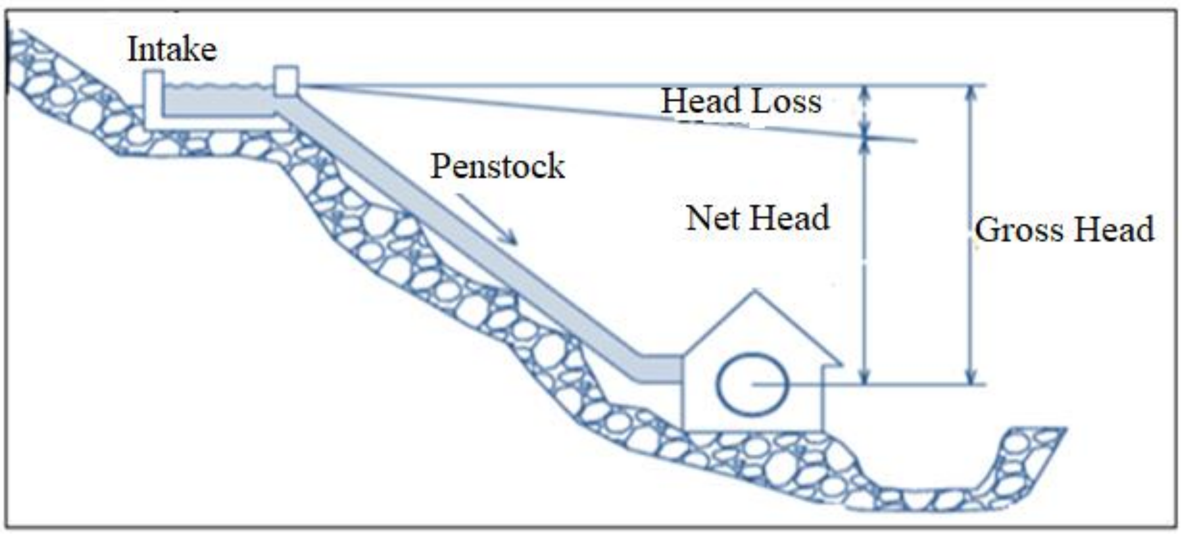


Figure 3. 4 Effective head after pipe loss (guidebook, 1998)

3.4.2.3 Stream Flow Rate Measurement

Stream flow rate refers to the volume of water that is flowing through a stream or river at a particular point in time. It is typically measured in liters per second (l/s) or cubic meters per second (m^3/s) and can vary depending on a number of factors, including precipitation, temperature, and topography. Stream flow rate is an important parameter for understanding the hydrology of a particular watershed or river basin, and can have significant implications for water management and planning. For example, low stream flow rates can indicate drought conditions, which can have implications for agriculture, water supply, and ecosystem health. Stream flow rate can be measured using a variety of techniques, including stream gauges, acoustic Doppler current profilers, and tracer studies. Stream gauges are the most common method of measuring stream flow rate, and involve the installation of a device that measures the height of the water surface and converts it into a flow rate using a rating curve. In this study, the Average stream flow rate including monthly stream flow rate values has been taken from the Ministry of Water and Energy of Ethiopia (MOWE) as shown in Figure 3.4.

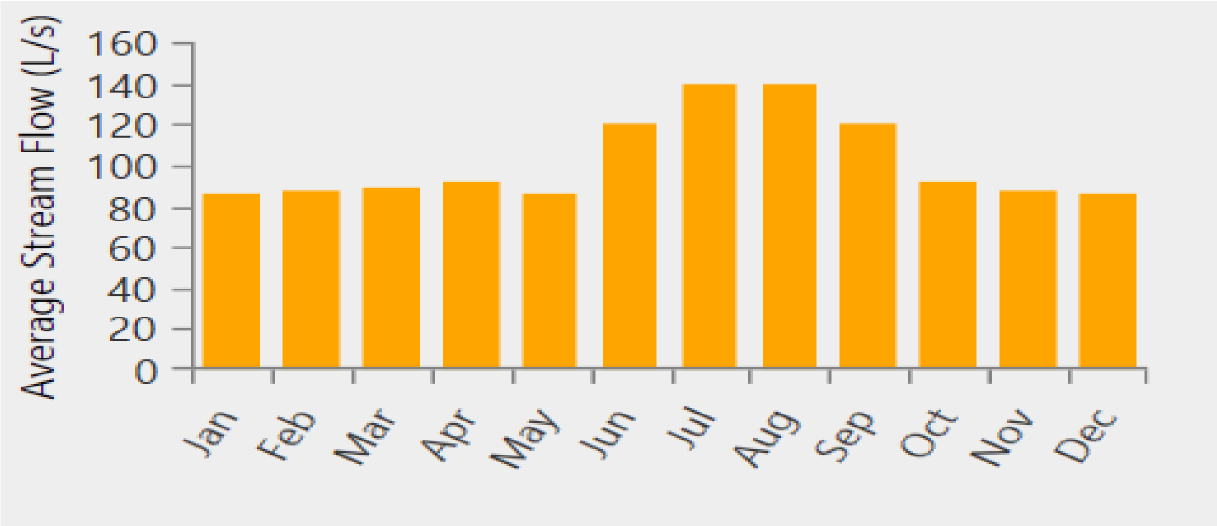


Figure 3. 5 Average stream flow (L/s), Source MOWE

3.4.2.4 Penstock Design

Penstocks (pipes) are used to convey water from the intake to the powerhouse. They can be installed underground, depending on factors such as the nature of the ground itself, the penstock materials, the ambient temperature, and the environment required for safety. The internal penstock diameter (Dp) can be estimated from the flow rate, pipe length, and gross head as considering steel penstock (np) ≅ 0.012, and the 60m length of penstock proposed (Singh, 2009)

$$dp = 2.69 * (np2 * Q2 * Lp/Hg)*^{0.1875} \text{ (m)} \quad (3.3)$$

Where np = Manning's coefficient. Q = Stream flow rate (m 3 /s). Lp = penstock length in (m). Hg = gross head in (m). Therefore, the diameter of steel penstock is 0.254m required. The wall thickness of the penstock depends on the pipe materials, its tensile strength, pipe diameter, and the operating pressure. The minimum wall thickness is recommended/preferable as:

$$t_p = \frac{dp+508}{400} + 1.2 \text{ (mm)} \quad (3.4)$$

Where Dp = penstock diameter in (mm) and tp = minimum penstock thickness in (mm), from this tp is 2.47mm. In addition to this, both the friction coefficient and the Reynolds number (Re) are required to calculate the head loss Once ∈/D (relative roughness) is determined, the friction coefficient can be gained from the "Moody Diagram" as shown in Appendix B. The Reynolds number "Re" is defined as (Ouma, 2011).

$$Re = V^* D/v \tag{3.5}$$

Where, D = A nominated characteristic length of the system (in the case of a hydropower penstock, the diameter), V= velocity of water in the pipe, and v = the kinematic viscosity of water= 1.004x 10^{-6} (m^2/s). Therefore, it reads the corresponding friction factor, which is 0.013, and head loss (hl) is calculated as follows

$$H_{f=} f *Lp * (Vp)^{2}/dp*2g \tag{3.6}$$

All necessary parameter was determined therefore, the head loss can be calculated based on equation 3.6, and therefore $H_{f=} f *Lp * (Vp)^{2}/dp*2g= 0.013 *60* 3^{2}/ 2*0.238*9.81 = 1. 41m$. Effective head (Hnet): The effective head is the actual vertical drop minus this head loss penstock which is calculated as follows

$$He=Hg-hl \tag{3.7}$$

Where Hg is Gross Head and *h*l is Head loss, therefore net head is 58.59m.

3.4.2.5 Turbine Power

All hydroelectric generation depends on falling water. Stream flow is the fuel of hydropower generation and without it, generation stops. Regardless of the water path through an open channel or penstock, the power generated in a turbine (lost from water potential energy) is given as (Nasir, 2013).

$$P_t = \rho * g * H_n * Q * \eta_t \,(watt) \tag{3.8}$$

Where P_t = power in watts generated in the turbine shaft, ρ= water density (1000 Kg/m^3), H_n = net head (m), Q = water flow rate (m^3/s), g = gravity acceleration constant (9.8 m/s^2), η_t = turbine efficiency

3.4.2.6 Turbine Type Section

Once the turbine power, specific speed, and net head are known, the turbine type, the turbine fundamental dimensions, and the height or elevation above the tailrace water surface that the turbine should be installed to avoid the cavitation phenomenon. Hydro turbines can be categorized mainly into two types: impulse and Reaction turbines. Impulse turbines are water applications. Compared to air reaction turbines, turbines are widely used for micro hydropower plants because they have many advantages, such as ease of design (no pressure seal around the shaft) and better access to work, ease to manufacture and maintenance, and more in water. Tolerance of existing sand and other particles and better part flow efficiency. The Pelton, Turgo, and cross-flow taurine are impulsive turbines. Based on a range of specific turbine speeds and effective heads, the **Pelton turbine** is appropriate.

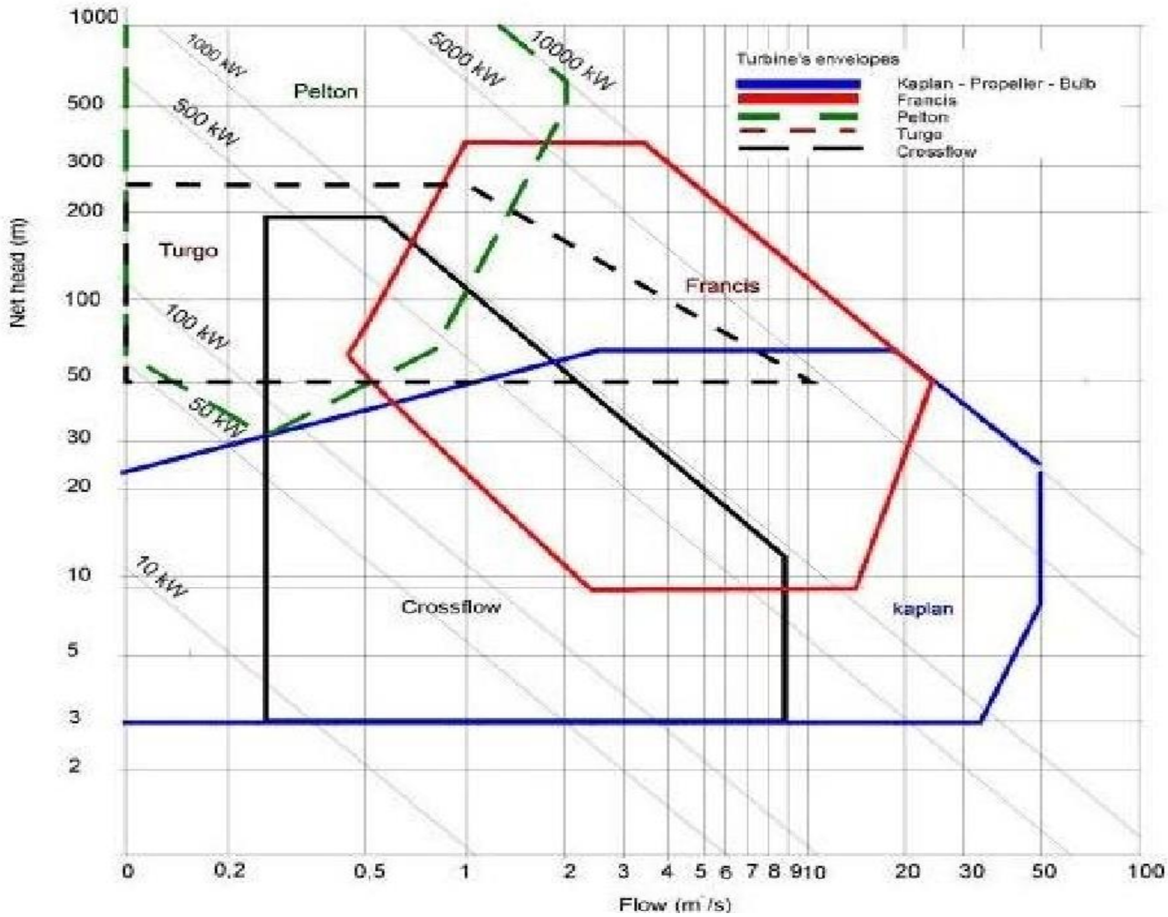


Figure 3. 6 Turbine selection chart (Bryan, 2013)

3.4.2.7 Total Power Output Determination

Necessary parameters were collected in order to calculate the power and energy of micro-hydropower for the village. The flow of water in the selected river is adequately high year-round so that the theoretical limit of power production does not limit the proposed project and we assumed the design flow rate to be $0.15m^3/s$ for the driest season of the year and the effective head is 58.59m. Therefore, Homer calculates the actual nominal power from the turbine is estimated as equation 3.9 below (Taken from Tilahun N., 2015).

$$P_{out} = \rho water * Q * H_n * \eta_{turbine} * g \quad (3.9)$$

Where, Pn= nominal power, ρ_{water}= density of water, ηt= hydro turbine efficiency, Hnet= gross head, and g= acceleration due to gravity, and flow rate (Q). Therefore, Nominal power [kW] = [58.59 m×1000kg/m3 ×9.81m/s2 ×150l/s×0.85] /1000 = 73.282KW from the design supply of Micro Hydropower plant. Therefore, another supply system should be explored to meet the village's electricity demand. Therefore, the electricity supply for the village is based on available resources of hydro and solar potential. As included in the design, battery storage, and diesel generator are also used for backup options. The capital cost of a wind turbine is higher than that of a PV system. Therefore, in our design system, PV is reliable and incurs lower costs relative to wind systems (Girm, 2015),

3.4.3 Solar Energy Resource Assessment

Identifying the potential site for solar energy development based on factors such as solar irradiances, land availability, proximity to transmission infrastructure, tilt angle, and free from shading. To determine the potential of solar energy generation for Kola Kinibibit kebele, it is important to assess the average total solar radiation received over the year. Therefore, global horizontal solar radiation data can be obtained from NASA (NASA, 2021G.C), the Photovoltaic geographical information system (2005-2020 G.C), the National Meteorological Agency of Ethiopia (Jimma, and Agaro branch), and HOMER-PRO software (July 1983- Jun2005). But, in this research, average global horizontal solar radiation was obtained from NASA -2021 G.C by entering Latitude 7.707269°N and Longitude 36.414828°E at an altitude of 1718 meters and is shown in Figure 3.6

Figure 3. 7 Monthly Average Solar Global Horizontal Irradiance data, Source (NASA 2021 G.C)

The village's monthly average solar resource was worst in July, which is 3.97kWh/m2/d in Ethiopia's summer, and the clearance index was obtained from NASA. From the analysis, the average solar radiation for the village is 5.23 kWh/m2 / day. See Table 3.10 below.

Table 3. 10 Village average solar radiation (NASA)

Months	Clearness Index	Average Radiation (KWh/m2/day)
Jan	0.597	5.48
Feb	0.591	5.78
Mar	0.564	5.82
Apr	0.544	5.7
May	0.524	5.38
Jun	0.47	4.73
Jul	0.392	3.97
Aug	0.412	4.25
Sep	0.472	4.87
Oct	0.573	5.67
Nov	0.599	5.56
Dec	0.615	5.5
Annual Average(kWh/m2/day) 5.3		

3.4.3.1 Radiation Incident on the PV Array

The GHI is the total amount of solar radiation streaking the horizontal surface of the earth. Nevertheless, the power generation of a PV array depends on the amount of radiation reaching the PV array, which is not necessarily horizontal.. Therefore, in each time step, HOMER-PRO software calculates when the global solar radiation incident on the surface of the PV array is known. The orientation of the PV array can be specified with two parameters such as slope, and azimuth. The slope is the angle formed between the surface of the panel and the horizontal surface, so a slope of zero indicates a horizontal orientation, whereas a 90° slope indicates a vertical orientation. HOMER uses the convention that zero azimuths correspond to south, and positive values indicate westward directions. Irradiation values on the horizontal plane will be sufficient for countries with latitudes between zero (0°) and +/- 10o (near the equator). In such cases, the module will be installed at a very small degree of inclination (10o from the horizontal).In countries where the latitude is greater than 10°, the module will often be inclined to an angle equal to the latitude of the site in order to receive the maximum irradiation throughout the year . The azimuth (γ) is the orientation, which is supposed to be followed by the placement of panels in terms of slope. Sites in the North hemisphere orient the PV towards the

South, while in the southern hemisphere, it is oriented north facing. Therefore, the azimuth (γ)orientations with 0° for the south, -90° for the east, 90° for the west, and 180° for the north (HYRESS, hybrid Renewable Energy Systems for Supplying of Services, 2008). Thus in this case study, the panels have no tracking system and are modeled as fixed tilted due south atazimuth0° with a slope of 8.85°, but in this study, the slope is taken 15°

3.4.3.2 Determining PV Power Output

The solar resource data is the average amount of sunlight hitting the horizontal surface at the bottom of the atmosphere (Earth's surface) each time step. HOMER uses the following formula to calculate the global radiation incidence on a PV array (Kimera, 2011):

$$P_{PV} = \gamma_{PV} f_{PV} G_T / G_{T,STC} (1+ \alpha_p) (T_C - T_{C,STC}) \quad (3.10)$$

Where,

α_p = The temperature coefficient of power [%/o C]],

γ_{PV}= The rated capacity of the PV array, meaning its power output under STC [kW].

f_{PV} = The PV derating factor in percentage [%].

G_T = the solar radiation incident on the PV- array in the current time step [kW/m2].

(Average solar radiation in peak sun hour's incident for specified tilt angle =5.23kwh/m2),

$G_{T,STC=}$ the incident radiation at standard test conditions [1 kW/m2],

T_C = The PV cell temperature [°C],

$T_{C,STC}$ = the cell temperature under standard test conditions [25°C], The following equation shows the relationship between the PV cell and ambient temperatures (HYRESS, HYRESS, (2008), hybrid Renewable Energy Systems for Supplying of Services, 2008):

$$TC = Ta + (0.0256 * G) \quad (3.11)$$

Where G is the solar radiation (W/m2). Monthly average air temperature over 30 years period (Jan 1984-Dec 2013 was obtained from HOMER- PRO-Software by inserting the selected site latitude and longitude as shown as follows.

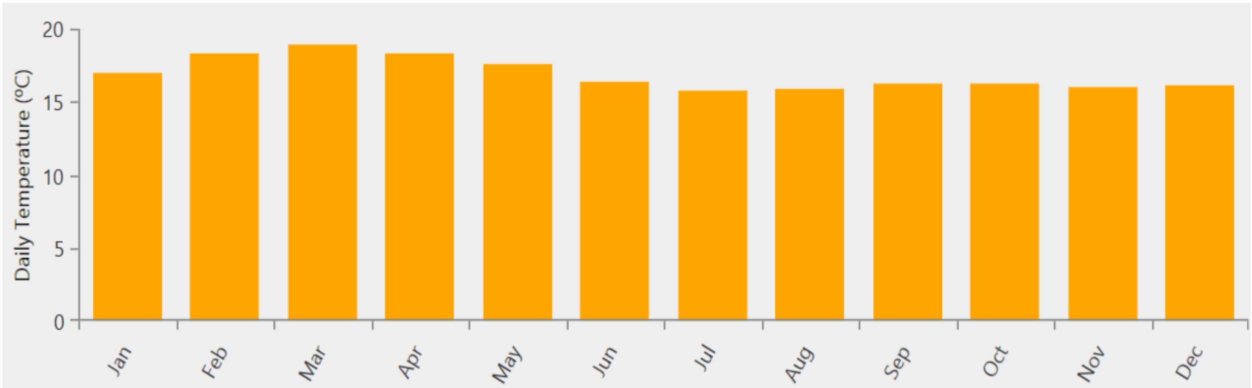


Figure 3. 8 Site Temperature Profile, Source from Homer-Pro software

3.4.3.3 Determining the Number of PV Modules in the System

After knowing the PV power output, the number of the PV module can be determined. The number of modules in series (Nms): The number of modules in series (Nms): The number of modules in series can be determined by the equation- 3.12 below. It is determined by dividing the designed system voltage V_{syst} (usually determined by the battery bank or the inverter). Where V_{nom} is the nominal module voltage at STC (Hadwan and A. Alkholidi, 2016).

$$N_{ms} = V_{syst} / V_{module} \tag{3.12}$$

The number of modules in parallel (Nmp): The number of modules in parallel can be calculated by equation 3.13 below. In other words, it is determined by dividing the designed array output by the selected module output and the number of modules in series.

$$N_{mp} = P_{pv}, \text{array} / V_{ms} * P_{module} \tag{3.13}$$

Where, Ppv, array = total power for PV array, P_{module} = Power of PV module, the Total number of modules of the system (Nmt) is given from equation 3.14.

$$N_{mt} = N_{ms*} N_{mp} \tag{3.14}$$

Finally, HOMER calculates the PV array outputs by using the above mathematical Formula.

3.4.4 Hybrid System Component's Characteristics and Costs Estimation

The characteristics and cost analysis of the hybrid power system requires a thorough detailed understanding of the energy resources, energy storage options, power electronics, and system design as well as a details analysis of hybrid power components and environmental impact considerations. The hybrid system components' characteristics and cost analysis are explained as follows:

3.4.4.1 Micro Hydro Power Plant Unit Cost

Since the cost of a micro hydro power plant differs according to various items, in which it is very difficult to know the cost of every one item. Because, most of the items require detailed understanding, in this project it is preferred to estimate the cost of a micro hydro power plant using other research that has been conducted on the cost per watt of the output power produced and the literature review on Micro hydro installation in Ethiopia. Micro hydro power plant installation in Ethiopia costs about US$1,200 per kW, and this is about half of the installation cost of other power plants built in eastern Africa (link). In addition, the information from (Diaf, 2008), the investment cost for a micro hydro per plant can be estimated as $ 1136 per kW, replacement cost is 50% of capital cost and O & M cost is 10% of capital cost.

Moreover, internationally, an initial capital cost estimated for micro hydropower plants with is estimated to be between US$1500 to $2500/kW. 75% of this development cost is decided by the location conditions, and the remaining 25% is the cost of purchasing engineering components (the turbine, generator, electronic load control, manual shunt-off value, and other components). Thus in this development, the cost is taken as an average at $1200/kW by considering the remote area, and thus the complicated position of the village and neighboring areas. The capital cost, replacement cost, and O & M cost of the Micro Hydropower system are estimated to be $46,200, 23100, and $4620 respectively.

3.4.4.2 Solar PV Module Type and Cost Estimation

PV module selection depends on the performance characteristics given by manufacturers. The selection is actually based on the efficiency and maximum power output of the module. World's most efficient currently commercially available crystalline silicon PV module products are given in Appendix E. For this study, a PV module producer by Sun Power with model X21-335 is selected. Universities and independent research laboratories around the world compared the performance of solar panels from Sup Power against other technologies. The selection is based on the technical performance of the module and the prices of PV. The specification of the selected PV module is given in Table 3.11 below.

Table 3. 11 SPR-X21-335-BLK PV module type Specification at STC (Web)

DC Electrical Characteristic (at STC)	Value	Unit
Power at STC	335	W
Power at PTC	313.5	W
Number of cells	96	
Power Density at PTC	205.6	W / m2
Vmp: Voltage at Max Power	57.3	V
Imp: Current at Max Power	5.85	A
Voc: Open Circuit Voltage	67.9	V
Isc: Short Circuit Current	6.23	A
Nominal Operating Cell Temp	45	°C
Open Circuit Voltage Temp Coefficient	-0.197	% / °k
Short Circuit Current Temp Coefficient	0.05	% / °K
Peak efficiency	20.56	
Max Power Temp Coefficient	-0.25	% / °K
Maximum System Voltage	600	V
STC = Standard Test Conditions: irradiance 1,000 W/m², AM 1.5 and Tc 25°C		

Therefore, the PV type determined in this case is Sun of Power with model X21-335 with an efficiency of 20.5% is $2/Watt. In addition, other costs such as labor, installation, structure costs, and civil work also have a significant portion of the capital costs. Other cost accounts for 22%of total module cost. Generally, PV capital cost is given as PV capital cost (kW) = PVsyst + other costs = 2000$/kW + 429$/kW = 2429$/kW. According to Department's National Renewable Energy Laboratory (NREL), the modeled costs to install solar photovoltaic (PV) systems continued to decline. The continuing, total cost decline of solar PV systems demonstrates the sustained economic competitiveness of solar PV. The global weighted average cost of off-grid PV year-to-year nominal cost decline. Therefore, the PV cost could decline by 43% from 2009 to 2016 (NREL, 2016). Thus based on an interview done with the MoWIE of Ethiopia, we assumed the project could be implemented after three years. Due to this, PV cost could decline by 18% from 2017 levels by 2020. By 2020, the PV cost is estimated at $1991/kW. In the study, the replacement cost is taken as 60% of the PV price and the operation and maintenance cost would assumed zero (AK Akella, 2010). The replacement cost and O & M costs are 119$/kW and $0/kW respectively. There are various investment incentives in Ethiopia: Tax-free importation of capital goods (Tsegaye, Samson Tsegaye (2016), Country Director, Solar Energy Foundation, Ethiopia June 27-29, 2016). Thus, considering the transport cost of 20% (Odax Ugirimbabazi, 2015), the total cost for 1kW comes to $2500and the replacement cost is about $1500.

3.4.4.3 Converter Cost Estimation

The power conditioning units are electronic devices and grouped into DC-DC/AC, AC/DC/ the DC/DC converters are electronic devices used to change DC voltage or current into needed voltage and frequency outputs. The DC/AC converter uses to switch the DC voltage or current produced by the hybrid system to the AC-type voltage output. This type of power converter is called a power inverter. The AC/DC power converter functions as an inverse of the inverter and it is called a rectifier. Inverters for the solar electric system are also divided into four types depending on their application: Standalone, Grid-connected inverter, hybrid power Grid interactive inverter. With this project, we will use a Hybrid power converter, which is good for the combination of solar and hydropower or diesel generators or any other RE source. In this study, the System Converter Capital cost is $245/kW, Cost of replacement is $245/kW, Efficiency is 90%, O&M cost per year is $10, and Lifetime is 10 years had been taken (L. Olatomiwa, L. Olatomiwa, R. Blanchard, S. Mekhilef, and D. Akinyele, "Hybrid renewable energy supply for rural healthcare facilities: An approach to quality healthcare delivery," Sustain. Energy Technol. Assessments, vol. 30, no. February, pp. 121–138, 2018, 2018). The converter is sized by Homer-pro software when the diesel generator and mains are output known.

3.4.4.4 Battery Storage Type and Cost Estimation

The method of electricity storage is to use electric rechargeable batteries, especially when PV modules produce the DC current required for charging the batteries. Most of the batteries used in PV systems are lead-acid batteries. In some applications, for example when used in locations with extreme climate conditions; or where high reliability is essential nickel-cadmium batteries are used. The major difficulty with this form of storage is the relatively high cost of the batteries and the large amount required for large-scale applications (T., 2011).

The following factors should be considered while choosing a battery for a PV application, they are-

Battery capacity: Batteries used in all solar systems are sized in ampere-hours under standard test conditions of 250 C. Battery manufacturers usually specify the maximum allowable depth of discharge for their batteries.

The depth of the discharge is a measure of how much of the total battery capacity has been consumed. A day of autonomy is the minimum number of days that should be considered for even the sunniest locations on Earth.

The number of days of autonomy that should be considered for on earth is 2-5 days (Ishaq M., 2013). The battery bank capacity required (Cx) is given by:-

$$C_X = \frac{(Abatt * El)}{DODmax * Vsyst * \eta batt} \tag{3.15}$$

El Is Estimated load energy in [kWh], DOD= Maximum depth of discharge, $\eta batt$ is Battery efficiency, = $Vsyst$ system voltage, $Abatt$ is a number of days of battery autonomy.

The battery bank autonomy is the ratio of the battery bank size to the electric load. HOMER calculates the battery bank autonomy using the following equation: (Ayodele T. R., Ayodele, T. R., & Ogunjuyigbe, A. S. O. (2014), Mathematical methods and software tools for designing and economic analysis of hybrid energy system. International Journal of Renewable Energy, 9(1), 57-68, 2014), (Homer, 2009).

$$A_{batt} = \frac{Nbatt * Vnom * Qnom * (1 - (\frac{qmin \ * 24hr/day}{100}}{El,avg \ * 1000Kwh/day} \tag{3.16}$$

Where, Nbatt= number of batteries in the battery bank, Vnom= nominal voltage of single battery [V], Qnom= nominal capacity of single battery [Ah], qmin= minimum state of charge of battery bank [%], and EL is the average primary load [kWh/d]. All related costs and the size of the load battery were estimated using Homer-Pro software.

The storage battery chosen is Surrette 6CS25P from the manufacturer Rolls/Surrette. This battery has a very high capacity compared to other battery storages in the HOMER tool library (HOMER® Pro, 2009). Dual-case replaceable cells small footprint and an expected life of over 10 years (depending on maintenance and application). The selected battery has the following characteristics obtained from the HOMER modeling tool. The nominal capacity of this battery is 820Ah (6.94kWh), the maximum charge current is 41S, a lifetime throughput of 9645 kWh was considered, the minimum state of charge is accounted for 40%, and round-trip battery efficiency is taken as 80%. The capital cost of $1100/Battery, the replacement cost of

$1100/Battery, and assuming maintenance cost of $10/hr (Salisu, 2019).

3.4.4.5 Charge Controller (Maximum power point Tracking)

The charge controller regulates the electric current that is following into and out of the battery bank. By controlling the rate of electric current, charge controllers prevent overcharging and can protect against over-voltage, which could damage the battery or motor. A charge controller can also prevent totally draining/deep discharging a battery, or perform controlled discharges, depending on the battery technology, to protect battery life (Ashok, Ashok, S. (2007) 'Optimized model for community-based hybrid energy system', Renewable Energy 32 (7), pp. 1155-64, 2007). The solar charge controller is about 3 to 5% of the whole solar system cost. However, investing in a quality controller ensures good battery management, which extends battery life and reduces associated costs. This solar charge controller performs crucial system functions such as low voltage disconnection (LVD) to protect the battery from deep discharge, and high voltage disconnection (HVD) to protect the battery from overcharging (Cook, 1998).

3.4.4.5 Diesel Generator Type and Cost Estimation

Generac Protector Diesel 15kw Price in Ethiopia is 509,340-birr on online store offers. It runs on natural gas or liquid propane (LP) fuel and sits outside just like a central air conditioning unit. It has an RD01525 engine that yields up to almost 39 hours of run-time with a fuel tanker capacity of 0.85 gallons. It allows you safety and efficiency from the control panel without the need for additional accessories with an outlet less than 5% THD. This diesel generator is completed with a 5-year limited warranty. For more, please refer to the link: https://electroprices.com/et/electric-generator/generac-protector-diesel-15kw-20. The lifetime of the diesel generator is taken as 15,000hr (Mutasim Nour G. R., 2014), the Operation and Maintenance cost is $0.015/kW/h, and the Minimum load ratio is 25% (Bhandari, 2014).

3.4.5 Feasibility Analysis of Hybrid Power System Configuration

Feasibility analysis of a hybrid power system requires a comprehensive evaluation of technical, economic, and environmental factors involved, as well as an assessment of the availability of resources and regulatory and policy considerations. The analysis should also include risk assessments to identify potential challenges and limitations of the system. It is important to consider the environmental impacts of the system, such as the potential for noise pollution, air pollution, and water pollution Therefore, the feasibility of a hybrid power system was demonstrated and all hybrid components were sized using Homer Pro software.

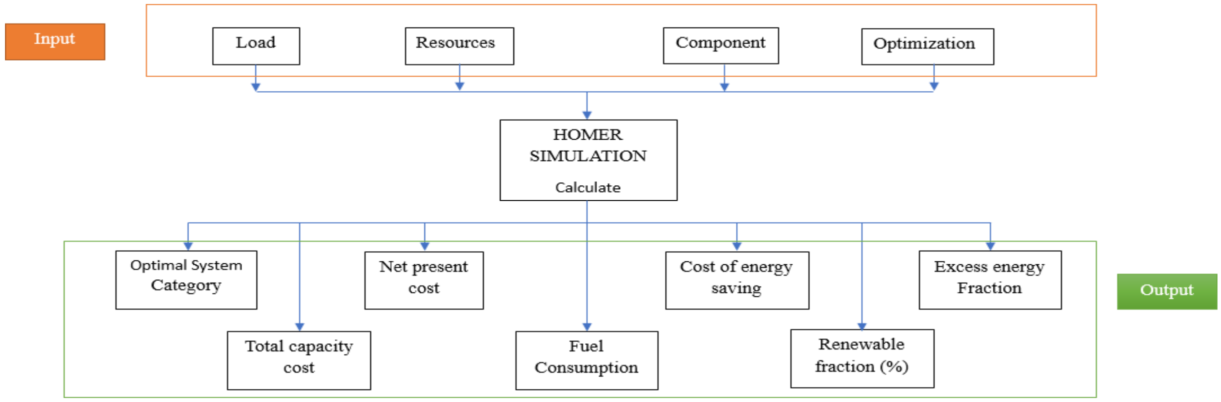


Figure 3. 9 HOMER simulation flow concept [(O. Erdinc and M. Uzunoglu, 2012)- (HOMER Energy LLC, 2016)].

Hybrid power System configuration: To analyze hybrid power system, HOMER requires information like energy resources, economic constraints, and control methods, including village load demand, renewable resources, component technical details, costs, and type of dispatch strategy. Thus, the Hybrid Energy system modeled in this system is Micro-Hydro/Solar+/battery storage /Diesel configuration as shown in Figure 3.9 below.

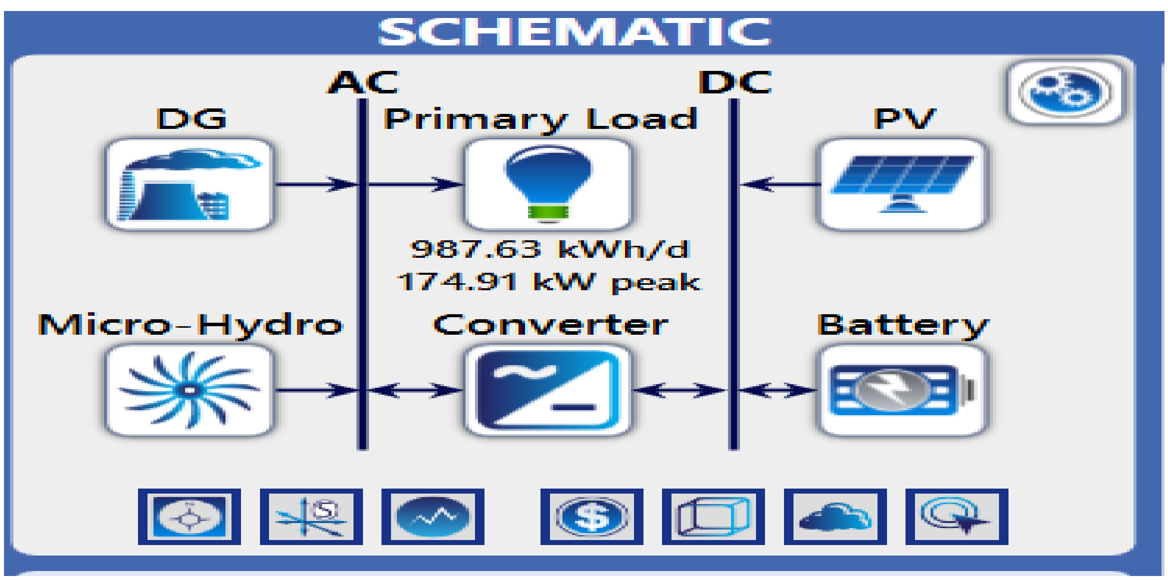


Figure 3. 10 Hybrid system design topology for the village, from Homer

Load Demand Input to the HOMER Software: The load during the yearly school break in July, August, and January will be compensated by load consumption during a weekday evening class at school. The daily and hourly noise (load variability) inputs allow for the addition of randomness to the load data to make it more realistic. Therefore, in this study, 0% hourly and 0% daily load noise is assumed; because the load demand is calculated by considering the variability of load demand. Each hour, Homer calculates the power produced by the elements of the system to serve the total primary load. Importing the load data into Homer's hourly load profile for the whole year is required from Appendix A. A load demand of 8,760 hours was thus created for a year based on hourly estimated load for different months. The load type served is AC and it varies during the summer and winter months. The load demand is approximately 987.63 kWh/day and 174.91 kW peak and a load factor of 0.24. Low-load factor customers would benefit from a battery energy storage system to distribute electrical usage out over longer intervals of time and smooth the peaks. The daily hourly pattern and the seasonal profile are shown in Figure 3.10.

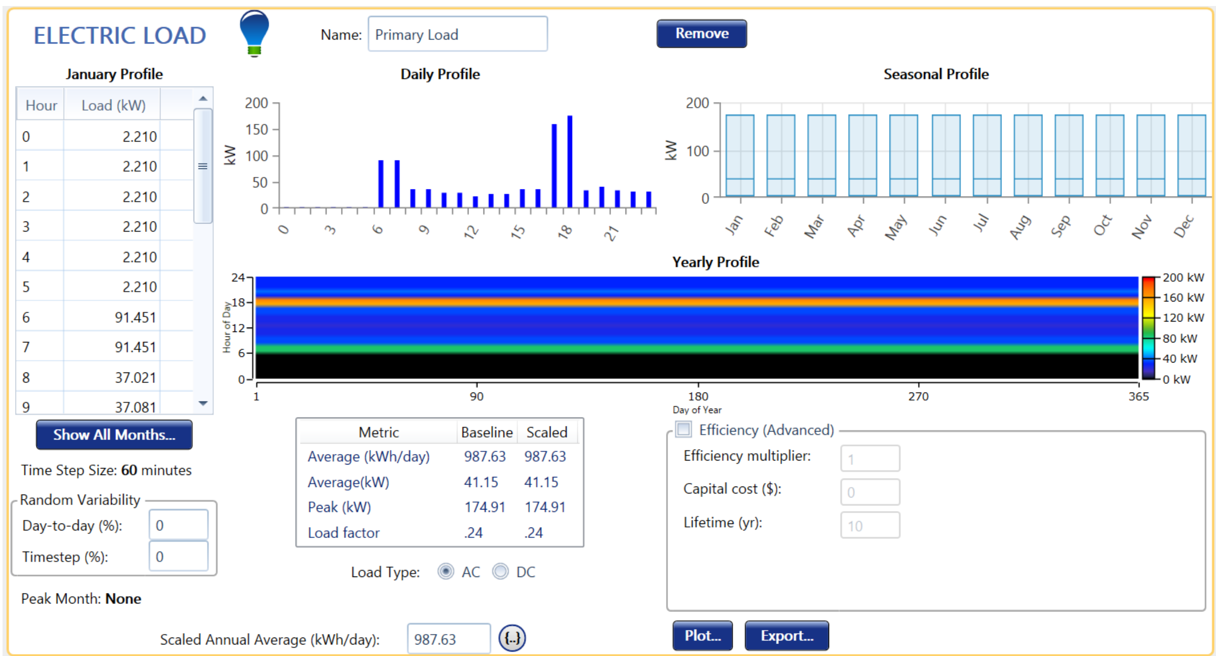


Figure 3. 11 Load profile for a typical primary load in Kola-Kinibibit kebele

Renewable Energy Resources: To obtain solar energy, GHI and the temperature input of the selected location are required. The required resources have already been discussed in Figures 3.8 and 3.9 respectively. Average stream flow is an essential resource to obtain hydroelectric energy as it is shown in Figure 3.5.

Hydropower data input into Homer Pro software: HOMER-PRO can be used to model and optimize the performance of micro-hydropower plants by inputting the key components and parameters of the system. The software can be used to evaluate the system's technical and economic feasibility and identify optimal design and operation strategies. Key components and parameters are capital cost, replacement cost, Operation and maintenance (O&M) cost, Pipe head loss (m), available net head (m), design flow rate (l/s), lifetime, and efficiency as shown in Figure 3.11.

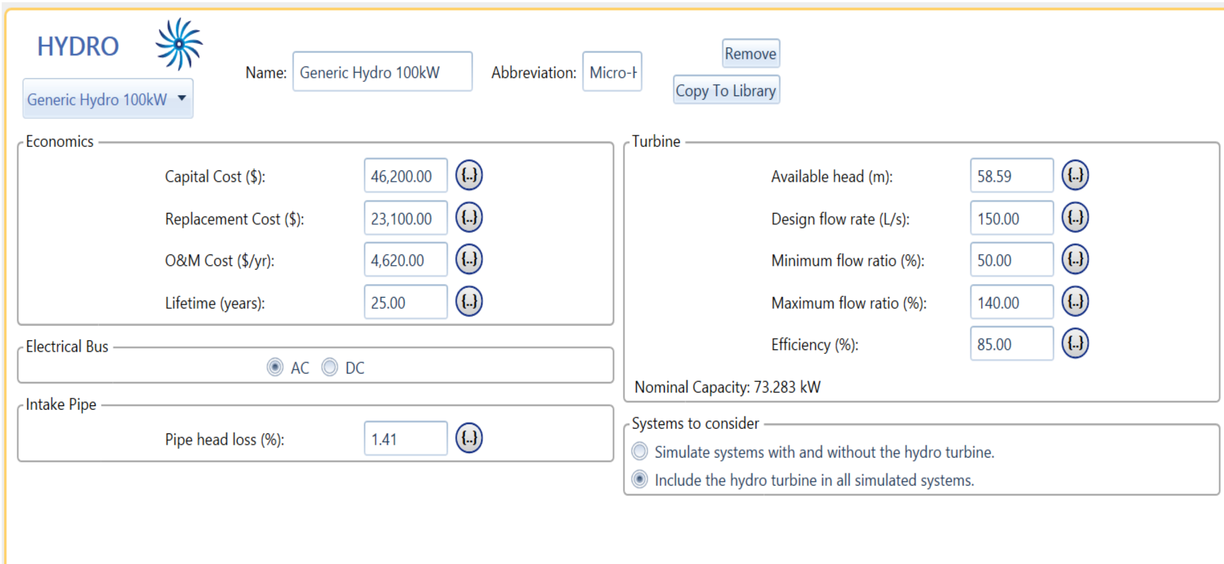


Figure 3. 12 Hydro input into Home-Pro software

Solar PV data Inputs into Homer-Pro Software: In the case of Ethiopia by taking a latitude greater than 10° and the system as a fixed-slope system, an approximation of slope equal to the latitude of the location. Thus the panels have no tracking system and are modeled as fixed tilted due south at 0° with a slope of 15°. The key parameters that were inputted into Homer-pro software are Capital cost, replacement cost, operation and maintenance cost, Charge control, lifetime, Derating factor, temperature, and GHI as shown in Figure 3.12. The capital cost, replacement cost, and operation and maintenance cost including the controller cost was discussed in the previous section.

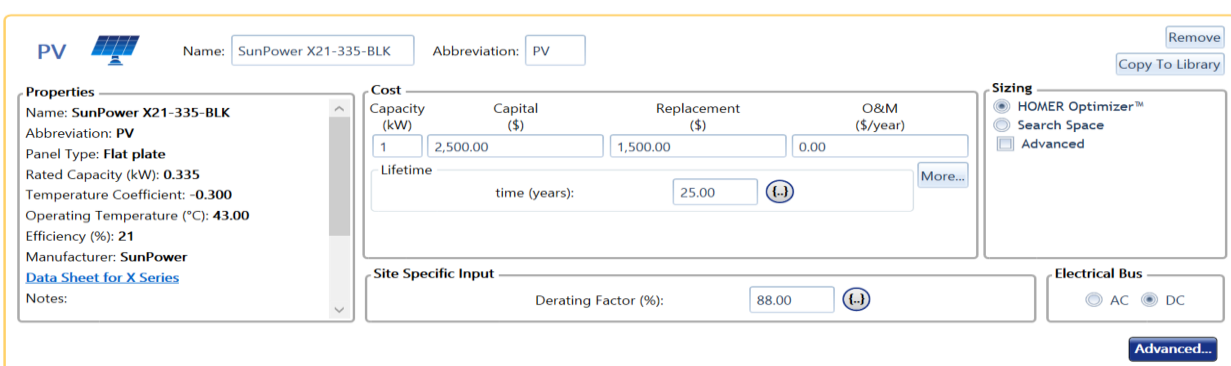


Figure 3. 13 PV Module input into Homer Pro-Software

Diesel Generator cost estimation and Input Parameter to Homer : In this section, Homer allows users to enter the cost, characteristics, and performance of a diesel generator. Generator Minimum Load is the minimum percentage of rated capacity for the generator for good functioning. The existence of this parameter is required because some manufacturers recommend that their machines, not be operated under a certain load. Lifetime is the number of hours that can be considered by the generator during its life and the manufacturers of diesel generators usually provide this number of working hours in their product brochures or data sheets. The lifetime of the selected generator is 15,000 hours. In this project, the cost of O&M is $ 0.0150/hr. The current diesel price in Ethiopia is estimated as $ 0.72/l (Mutasim Nour G. R., 2014), but it was taken as 1$ per liter.

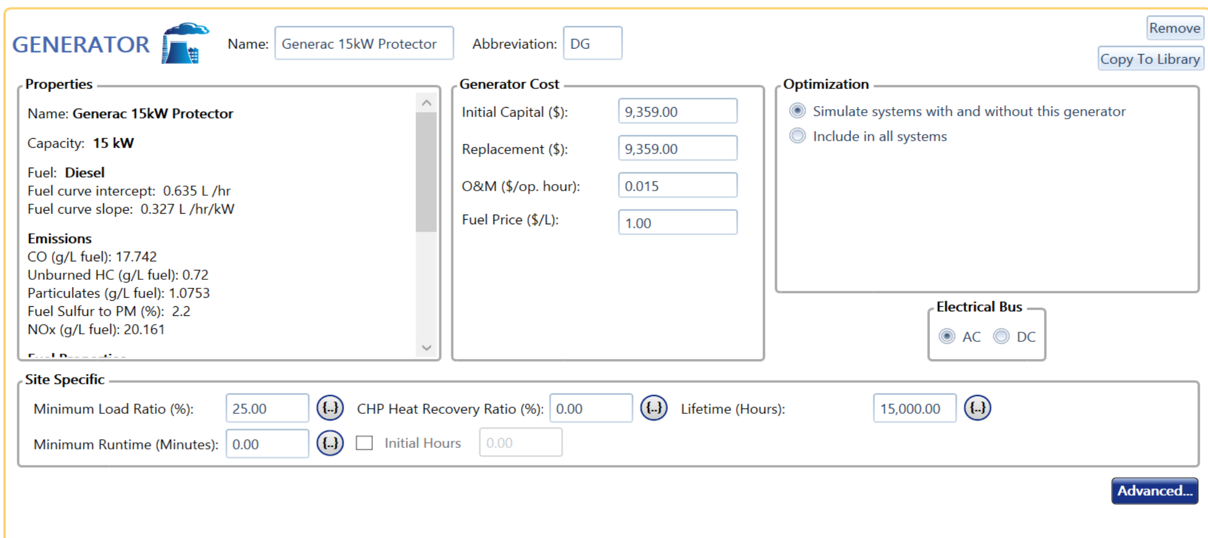


Figure 3. 14 Diesel generator inputs into HOMER-Pro software

Battery data loaded to Homer: In this study, a Surrette 6CS25P of 6V has been selected and 48V system voltage, which requires eight batteries in the string. In the figure below, this window helps to indicate the cost of the battery. I have entered an amount of one battery for capital, replacement, and O&M costs, the cost of one unit battery cost is about $ 1,100 initially, $ 1,100 for replacement, and $ 10 annually for O&M as shown in Figure 3.14 (O. Oladigbolu, 2019).

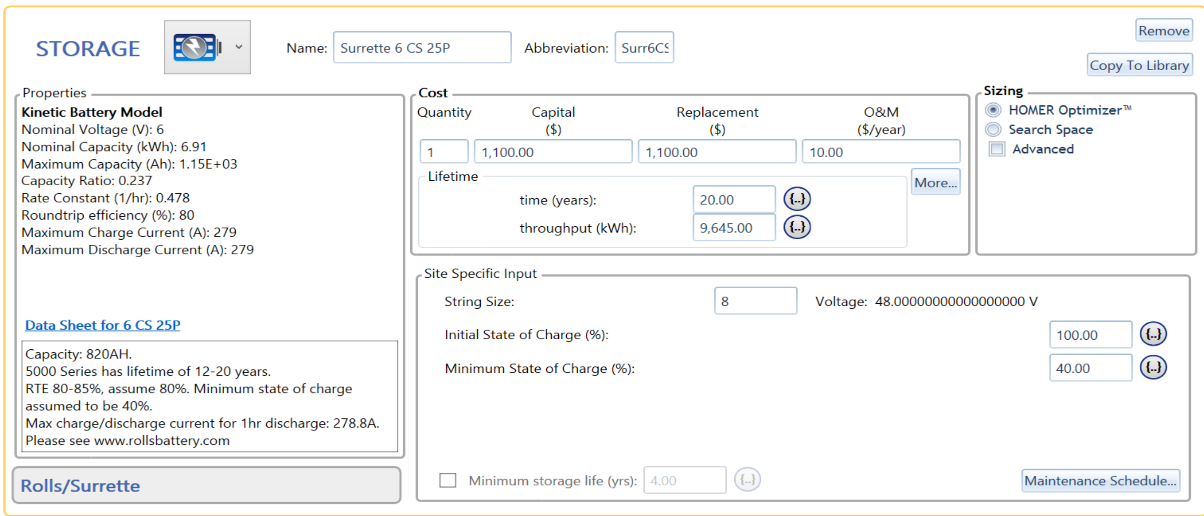


Figure 3. 15 Storage battery input window, from HOMER

Converter Inputs: In this study, power electronic System converter per kilo-watt capital cost, replacement cost, and operation and maintenance cost are 245$/kW, 245$/kW, and $10 respectively. The lifetime of the converter is 10 years with 90% efficiency (L. Olatomiwa, L. Olatomiwa, R. Blanchard, S. Mekhilef, and D. Akinyele, "Hybrid renewable energy supply for rural healthcare facilities: An approach to quality healthcare delivery," Sustain. Energy Technol. Assessments, vol. 30, no. February, pp. 121–138, 2018., 2018).

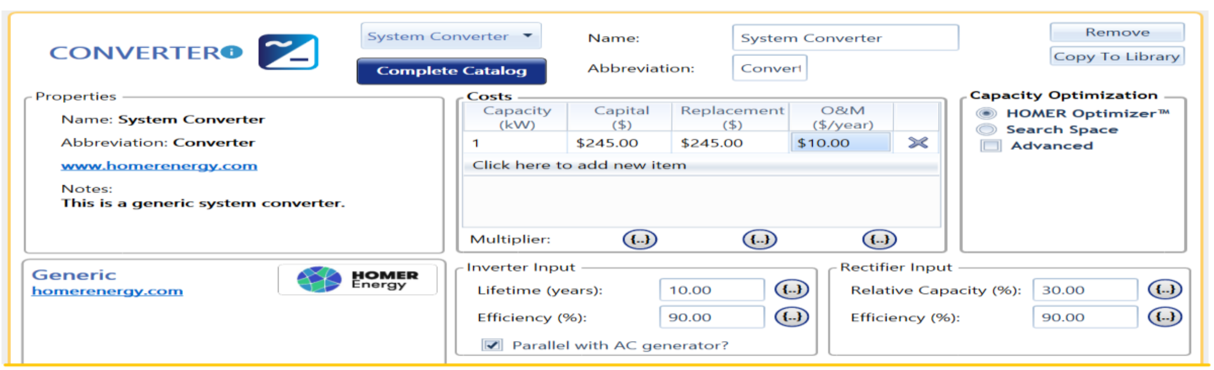


Figure 3. 16 converter input window, from HOMER

Economic Inputs: Homer considers the economic input to each system it simulates to calculate the system's net present cost. The lifetime of the project that has been studied here is about 20 years. Homer supposes the rate of inflation to be the same for all types of costs like fuel cost, maintenance cost, labor cost, etc. The real interest rate (percentage) in Ethiopia is about 5.0% (Tsegaye, Samson Tsegaye (2016), Country Director, Solar Energy Foundation, Ethiopia June 27-29, 2016).

System Control Inputs: The diesel generator is the only none renewable and dispatch energy source used in this hybrid energy system. Since the output, power from renewable sources is highly intermittent and cannot be controlled by the user. It has to be used when it is available for supplying the load. The optimal system depends on factors like the power size of the generator. Therefore, a dispatch strategy should also be developed when optimizing the hybrid system. Two dispatch strategies; 1) Cycle charging (CC), batteries are to be charged to the set point state of charge when the system starts to charge with no interruption until it will reach the set point state of charge. It helps to reduce the generator number of start cycles, charge and discharge cycles of the battery bank, and the time the battery waste at a minimum state of charge. 2) Load following (LF), this means batteries do not charge by the diesel generator, it gets maximum charging time when renewable sources get higher, meaning when generated power is greater than the load demand. In this study, as shown in Figure 3.16, both strategies have been selected to see which is more suitable in the given constraints of the system. The set point charge for the batteries is kept at 100% (Version, 2016)

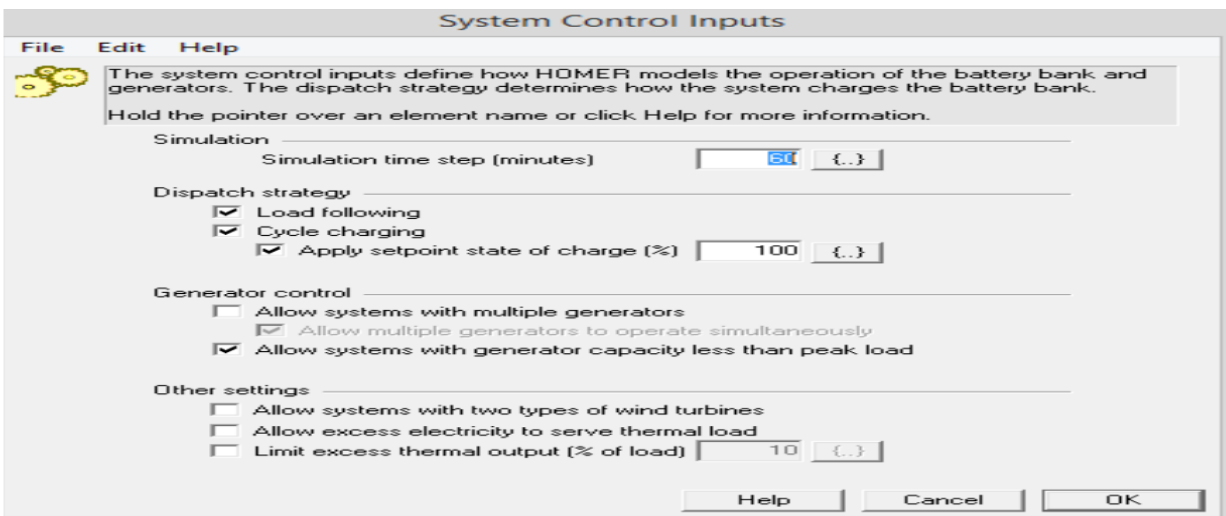


Figure 3. 17 System control input window, from HOMER

CHAPTER FOUR

4. RESULT AND DISCUSSION

4.1 Introduction

The optimized power generated from the hybrid components result has been selected based on less Net present cost NPC, the less minimum cost of energy COE, higher renewable fraction, less capacity shortage, smaller excess electricity, and minimum fuel consumption optimum system configuration and Optimized hybrid power System Outputs with its sensitivity analysis discussed in this section. The optimum entire hybrid system including solar power generation system, load battery, micro hydropower, and backup generator is simulated using MATLAB-Simulink software. Finally, the hybrid system as a whole is discussed with simulations of the operation time and Fuzzy controller system at the microgrid distribution system.

4.2 Optimization of Hybrid Power System Simulation Result

According to Homer's pro-Software calculation report, there were 1524 solutions simulated among them 741 were feasible, and 803 were infeasible due to the capacity shortage constraint. However, the simulation output is a list of feasible combinations of Micro-hydro/ PV/Diesel Generator/ Converter, and Battery hybrid system using homer pro software is shown in Table 4.1 below.

Table 4. 1 Hybrid Power System simulation result, HOMER PRO

Architecture							Cost				System			DG	
PV (kW)	DG (kW)	Battery	Micro-Hydro (kW)	Converter (kW)	Dispat		NPC ($)	COE ($)	Operating cost ($/yr)	Initial capital ($)	Ren Frac (%)	Cap Short (%)	Excess Elec (%)	Hours	Fuel (L)
45.1	15.0	160	73.3	126	LF		$862,098	$0.0966	$19,478	$375,151	99.1	1.09	11.6	269	1,264
50.5		192	73.3	130	CC		$862,506	$0.0966	$17,880	$415,513	100	1.06	12.4		
	15.0	144	73.3	113	CC		$1.64M	$0.184	$56,104	$241,544	76.8	1.06	11.3	8,743	32,661

4.2.1 Caparison of Scenarios for Economic Power Systems

From the simulation result of Table 4.1, the considered systems based on the same input values are compared using the same variable cases in terms of techno-economic aspects from among the least cost results. It was compared in the case of Micro Hydro/Solar PV/Diesel Generator/Battery bank (system A) and Micro Hydro / Solar / Battery bank (system B), and Micro Hydro / Diesel Generator / Battery bank(system C) based on the following criteria.

Based on the total net present cost, the result indicates that the load demand of 987.63 kwh/d, a maximum capacity shortage of 1.0%, and a minimum renewable fraction of 60 %. The considered comparison parameters are discussed as follows in order to select a techno-economically feasible power system. As shown in Table 4.1, the configuration of the system (scenario A), has less net present cost are less than B system and System C, which is about $862.098.

Based on the cost of energy, to get detailed information on the COE for each power system refer to Table 4.1, system A has $0.0966 COE, system B has $0.0966, and system C has $0.184, almost equal costs of energy with small differences. However, systems A and B registered less COE than systems C.

Based on diesel fuel consumption, According to Homer Pro software calculated, system B was not a diesel generator configured, thus system B is preferable due to there being no gas emission.

Based on renewable fractions, based on a renewable fraction, system B has 100% renewable fractions, which is higher than systems A and C.

Based on excess electricity production; in this comparison parameter, electricity production is considered; the lowest excess electricity production is the optimal system, which is first selected is implement. Systems (A, B & C) have produced excess electricity of 11.60%, 12.4%, and 11.30 respectively.

Overall, based on economic compassion, which is less net present cost (NPC), the minimum cost of energy (COE), a high renewable fraction, less excess electricity, and less fuel consumption. The maximum annual capacity shortage and minimum renewable fraction are the worst constraints case, system A was selected, which is a Solar/micro-Hydro/battery/diesel generator including converter hybrid power configuration.

4.2.2 Optimized of Hybrid Power System Components Outputs

Hydro system output: This Micro Hydropower plant generates annual energy production is 387,128 kWh/year, which is the highest Percentage (107%) of the overall energy generated. This system can meet the load demand with an availability of around 100% resulting in only around 0 hours of power outage during a year.

Quantity	Value	Units
Nominal Capacity	73.3	kW
Mean output	44.2	kW
Capacity factor	60.3	%
Total Production	387,128	kWh/yr

Quantity	Value	Units
Minimum output	36.6	kW
Maximum output	62.6	kW
Hydro penetration	107	%
Hours of operation	8,760	hrs/yr
Levelized Cost	0.0167	$/kWh

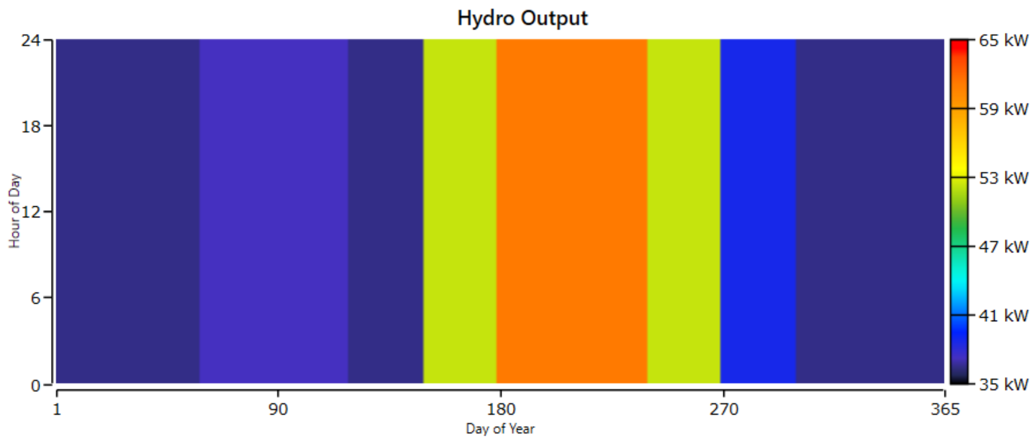


Figure 4. 1 Hydropower output Result from Homer Pro

PV output: The Solar PV system output was displayed from Homer-Pro software with a rated capacity of 45.1 KW and leveled cost 0.0600$/KWh as shown In Figure4.2

Quantity	Value	Units
Rated Capacity	45.1	kW
Mean Output	8.59	kW
Mean Output	206	kWh/d
Capacity Factor	19.0	%
Total Production	75,263	kWh/yr

Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	47.3	kW
PV Penetration	20.9	%
Hours of Operation	4,435	hrs/yr
Levelized Cost	0.0600	$/kWh

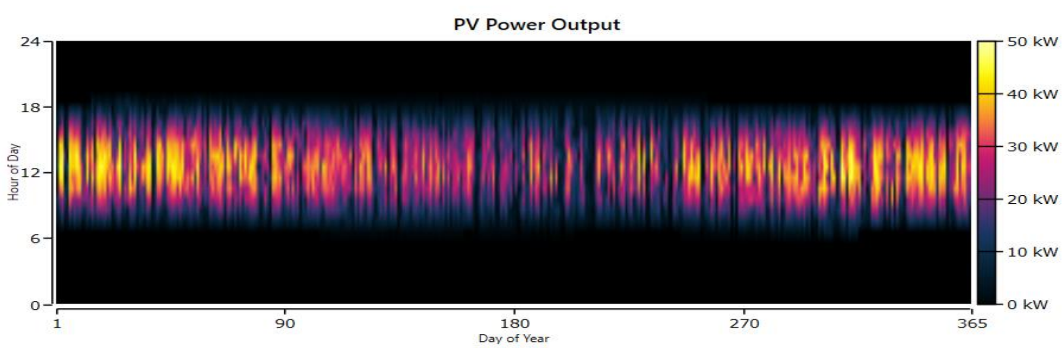
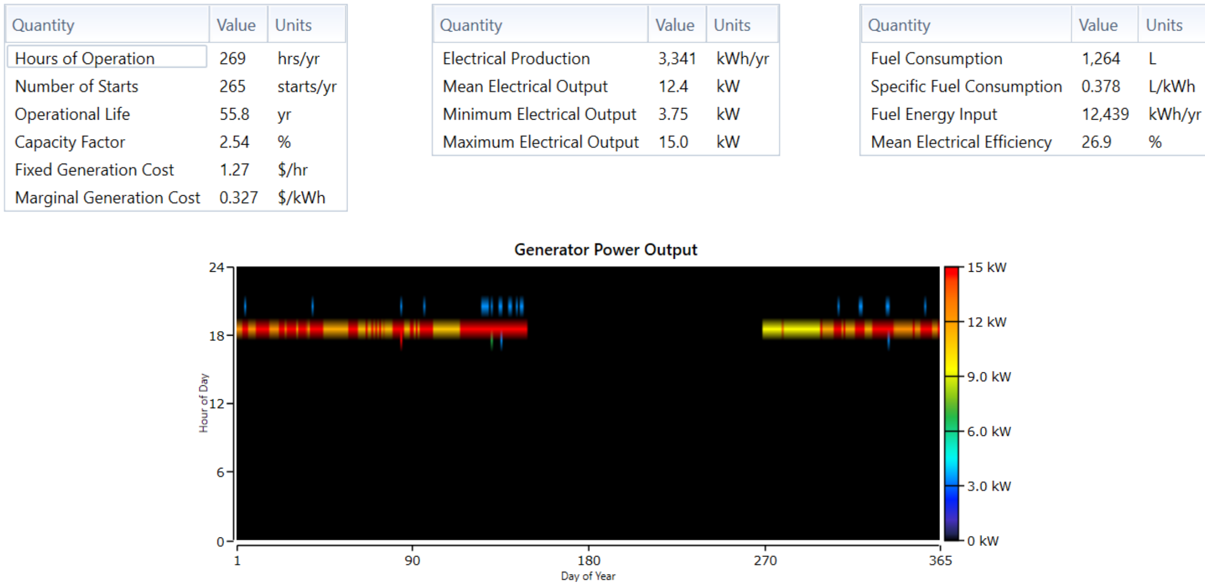


Figure 4. 2 Hourly and monthly solar power output Result from Homer Pro

Diesel Generator Output: The following Figure 4.3 shows the power output and diesel generator power of the system.



Quantity	Value	Units
Hours of Operation	269	hrs/yr
Number of Starts	265	starts/yr
Operational Life	55.8	yr
Capacity Factor	2.54	%
Fixed Generation Cost	1.27	$/hr
Marginal Generation Cost	0.327	$/kWh

Quantity	Value	Units
Electrical Production	3,341	kWh/yr
Mean Electrical Output	12.4	kW
Minimum Electrical Output	3.75	kW
Maximum Electrical Output	15.0	kW

Quantity	Value	Units
Fuel Consumption	1,264	L
Specific Fuel Consumption	0.378	L/kWh
Fuel Energy Input	12,439	kWh/yr
Mean Electrical Efficiency	26.9	%

Figure 4. 3 Diesel Generator output Result from HOMER

Battery Energy Storage System Output: The output of the load battery was displayed as a state of charge and Hours of the day as shown in Figure 4.4

Quantity	Value	Units
Batteries	160	qty.
String Size	8.00	batteries
Strings in Parallel	20.0	strings
Bus Voltage	48.0	V

Quantity	Value	Units
Autonomy	16.1	hr
Storage Wear Cost	0.128	$/kWh
Nominal Capacity	1,105	kWh
Usable Nominal Capacity	663	kWh
Lifetime Throughput	1,543,200	kWh
Expected Life	10.9	yr

Quantity	Value	Units
Average Energy Cost	0	$/kWh
Energy In	157,516	kWh/yr
Energy Out	126,523	kWh/yr
Storage Depletion	571	kWh/yr
Losses	31,563	kWh/yr
Annual Throughput	141,457	kWh/yr

Figure 4. 4 Battery output Result from HOMER

Monthly Electric production: AS shown in Figure 4.5 the monthly electric production indicated that the micro hydropower plant with a rated capacity of 73.3KW has 83.1%, the PV system has a rated capacity of 45.1KW 16.2 %, and the diesel generator with a 15KW capacity can handle 0.717%.

Production	kWh/yr	%
SunPower X21-335-BLK	75,263	16.2
Generac 15kW Protector	3,341	0.717
Hydro	387,128	83.1
Total	465,733	100

Consumption	kWh/yr	%
AC Primary Load	356,862	100
DC Primary Load	0	0
Deferrable Load	0	0
Total	356,862	100

Quantity	kWh/yr	%
Excess Electricity	54,025	11.6
Unmet Electric Load	3,623	1.01
Capacity Shortage	3,936	1.09

Quantity	Value	Units
Renewable Fraction	99.1	%
Max. Renew. Penetration	2,830	%

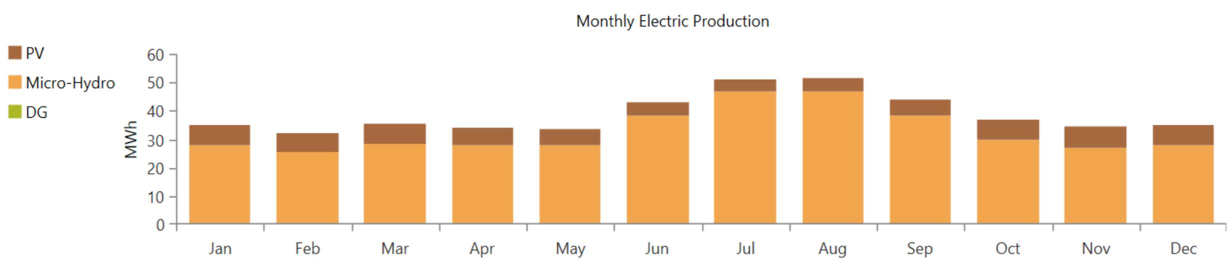


Figure 4. 5 The Hybrid Power system Configured of Monthly Electric Production

Optimization Analysis Based on the simulation result and comparison of the systems, annual electrical energy production, initial capital cost, excess electricity, renewable fraction, capacity shortage, annual fuel consumption, and operation hours of the generator are the criteria selected to select the systems. Table 5.1 is the displayed overall optimization result of all the promising configurations of feasible power schemes based on the total NPC of the system.

The result is for the selected system A based on the current diesel price of $1/liter, primary load demand of 987.63 kWh/year, maximum annual capacity shortage of 1%, and a minimum renewable fraction of 60%. The system configuration in the first row of table 4.1 is a cost-efficient system and technically composed of Micro hydropower with 73.3 kW, 45.10 kW photovoltaic panel, 15kW diesel generator, 160 unit batteries, and 126kW converter. From the result, the diesel generator runs in load following (LF) strategy and runs regularly the whole year due to during nighttime load sought because renewable energy sources stored in the battery are not enough to meet the load.

4.2.3 Solar PV and Diesel Generator Sensitivity Analysis

In this case, two sensitivity variables are considered. Those variables are the site's amount of solar radiation and the cost of diesel fuel. These two variables are considered to affect the cost of the system. The result of the sensitivity analysis is shown in Figure 4.6. The solar radiation of the PV array / micro hydro / DG/battery system reaches 5.23 kW / m2 per day and is very small when the price of fuel changes. Currently, the price of diesel fuel in Ethiopia is around 67 birr /liter. With diesel prices up to $1.2/L, the micro hydro/PV/DG/battery hybrid system is economical. Therefore, it is more economical to put a diesel generator into the system.

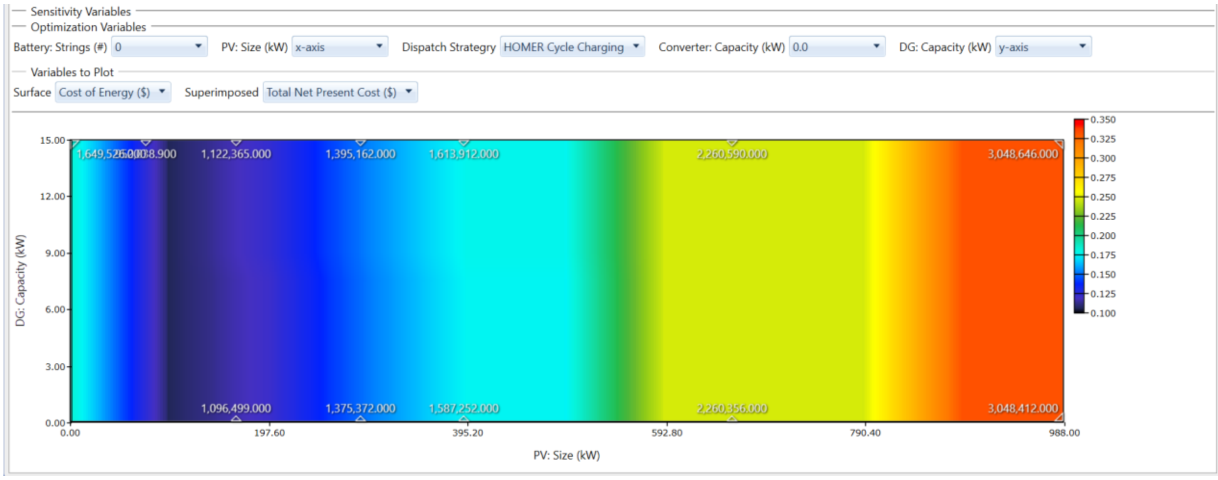


Figure 4. 6 Sensitivity Result

4.3 Hybrid Power System Simulation Result from MATLAB/Simulink

The power generation from the hybrid components and the fuzzy logic controller is simulated and discussed in the section below. First, the solar power system is modeled and simulated to give an output of around 45.1KW, and next micro hydropower system has a capacity of 73.3KW and a diesel generator capacity of 15KW power produced.

4.3.1 Solar Power Generation System

The location where the solar system had installed is selected based on solar radiation and from these technical specifications. The power generated from the solar panels (sun power SPR-335NX-BLK-D) is around 45.1KW of DC power. And to achieve this the short circuit current of the solar panel is 6.23A, the maximum current is 5.85A, the maximum voltage is 57.3V and the open circuit voltage is 67.9V with there are 135pieces of a number of solar panels required to connect 27 in parallel and 5 in series. The total array input voltage is 286.5 Vdc; the input current is 157.5A with a switching frequency is 5 kHz having a duty cycle of 63.5%. Therefore, the boost converter increased the input voltage to 500V with an inductor value of 1.9 mH, an input capacitor value of 1500 µF, an output capacitor value of 570 µF, and a resistor value of 6.3 Ω. The mathematical modeling of the boost converter using Matlab/Simulink is shown in Figure 4.7

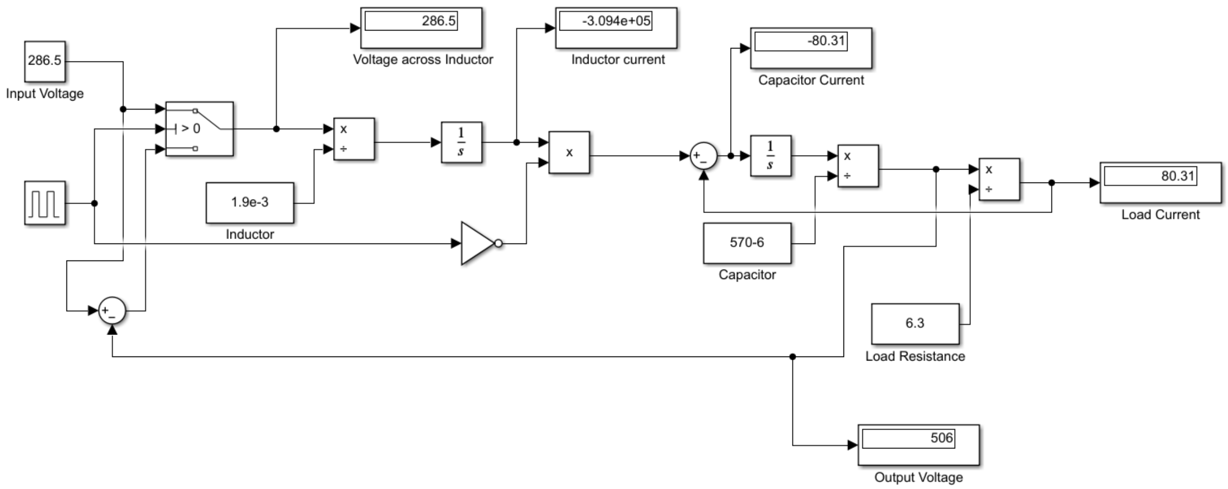


Figure 4. 7 Mathematical Modelling of Boost converter using MATLAB/Simulink

The Matlab simulation power generated from the proposed solar array is around 45.225 KW, and this is shown in the current versus voltage curve and in the power versus voltage curve as shown in figure-4.8.

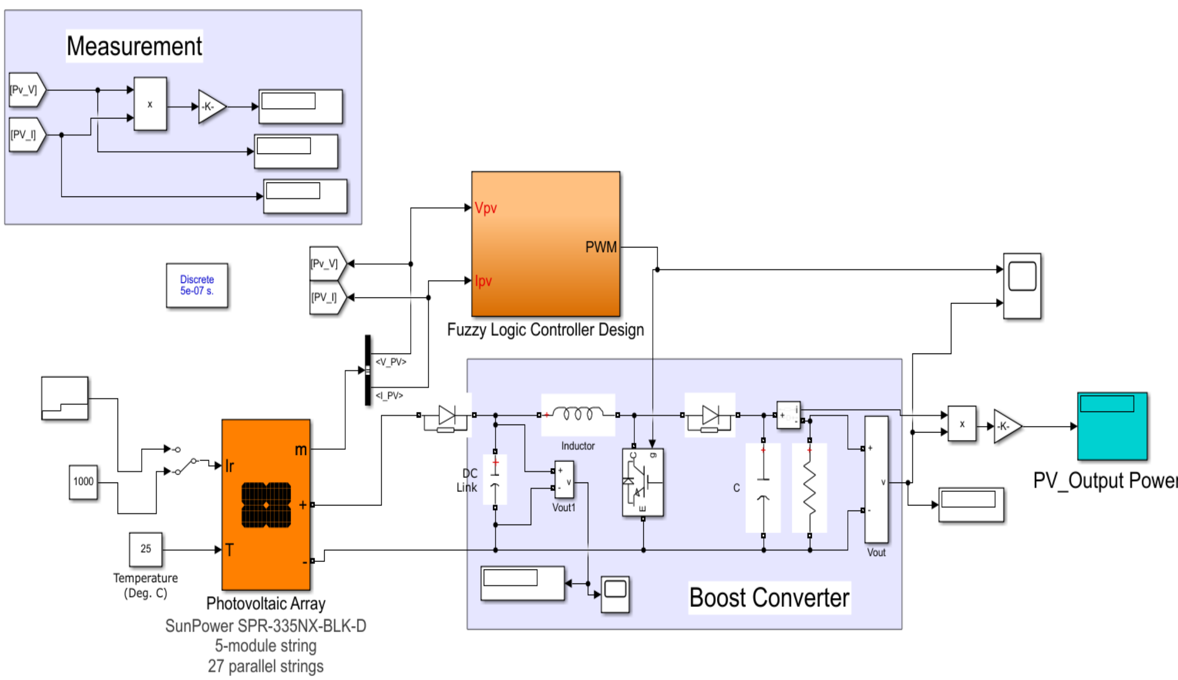


Figure 4. 8 Simulation Model of Solar PV system Using Matlab/Simulink

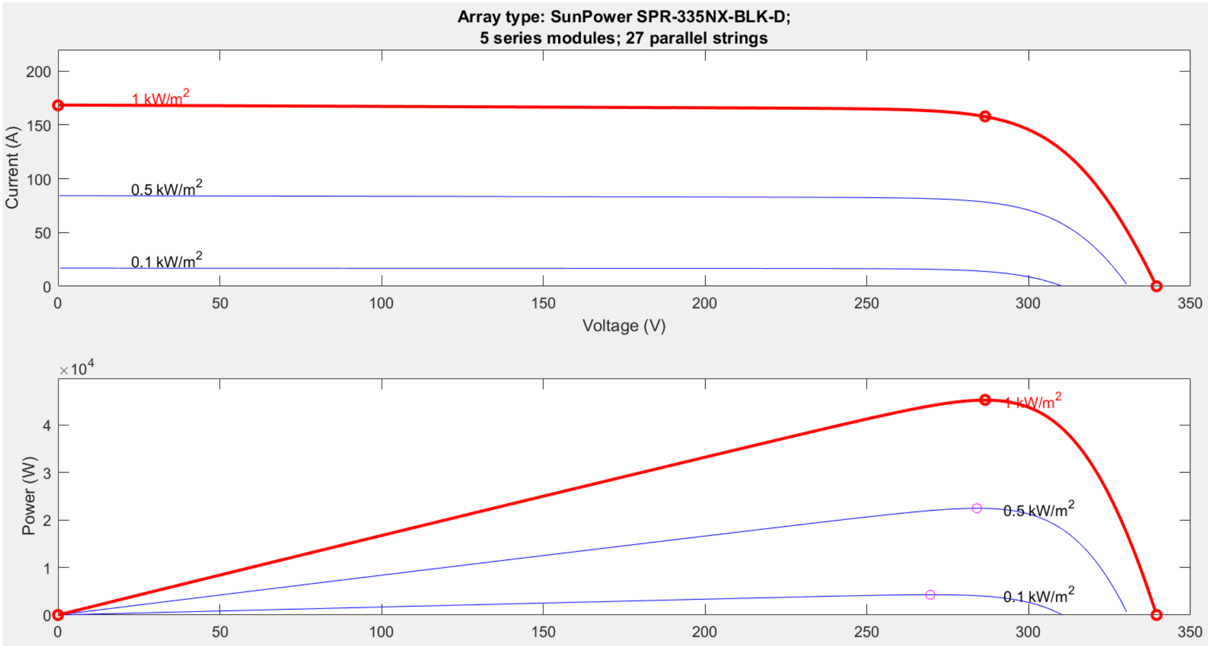


Figure 4. 9 V-I, and P-V characteristics curve of the solar-generated power.

4.3.2 Micro-Hydro Power Plant Generation

Hydropower plant mainly consists of a governor (controller), hydro servo system, and hydro turbine so-called hydraulic turbine and Governor, which is coupled to a synchronous generator to drive the shaft so that the mechanical energy of the turbine is converted to electrical energy with supplied power to a common electrical three-phase parallel RLC load models are simulated on MATLAB/Simulink. It has two main sections, firstly the mechanical part of the plant, includes a hydraulic turbine, penstock, controller, hydraulic servomotor, control valve, etc. The second part of the plant is the electrical section, which mainly consists of a generator and load. Here the PID controller is used as the controller. The error in speed is fed as input to the controller and the PID controller attempts to reduce the difference between the actual speed and the reference speed by adjusting the constants of the controller. P depends on the present error, I on the accumulation of past errors, and D is a prediction of future errors, based on the current rate of change. Therefore, micro hydropower plant modeling in MATLAB-Simulink, it must be designed with mathematical modeling of PID for the Governor controller, Gate opening using Servomotor, hydro-turbine, excitation, and synchronous generator using MATLAB /Simulink. As shown in Figure 4.9, completed micro-hydropower, which has a capacity of 73.3 KW, was simulated.

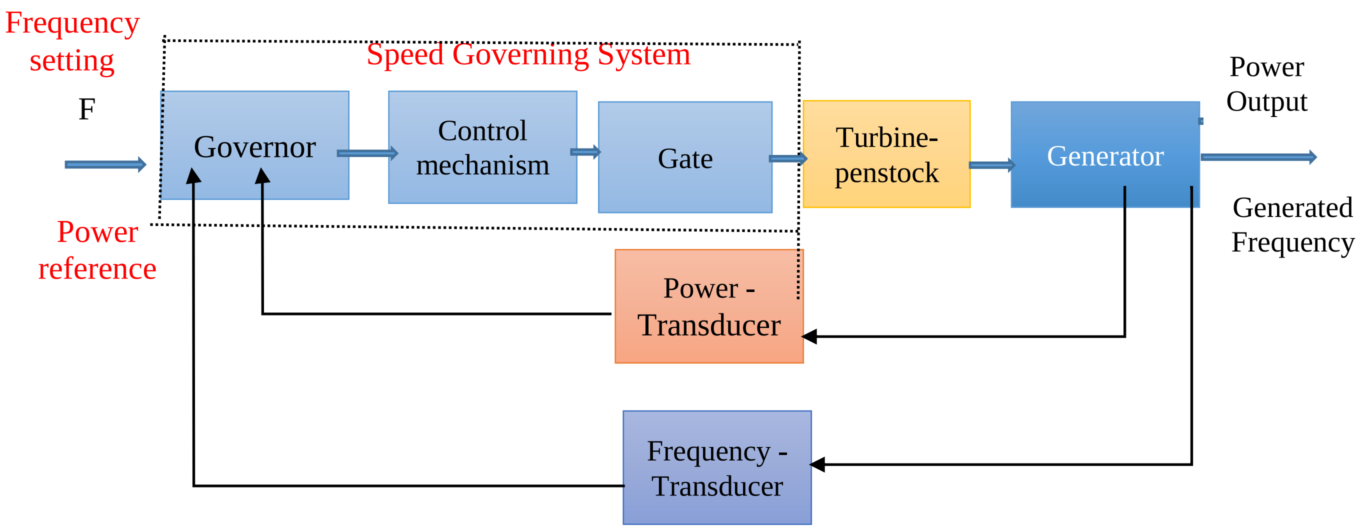


Figure 4. 10 Complete Functional Block Diagram of a Hydro Power Plant

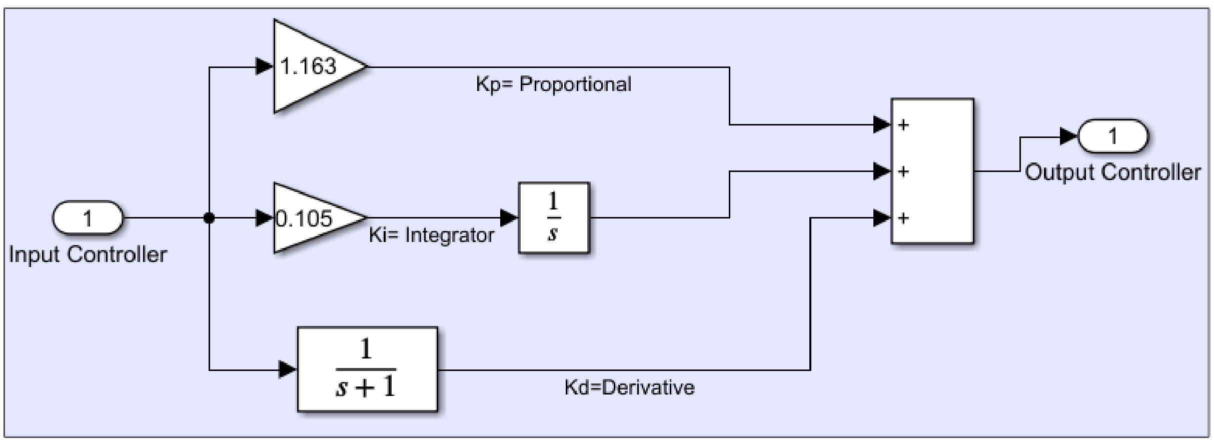


Figure 4. 11 Simulink Model of a Controller of Governor

The gate servomotor is modeled by a second-order system shown in figure 5, which used to gate opening for turbine.

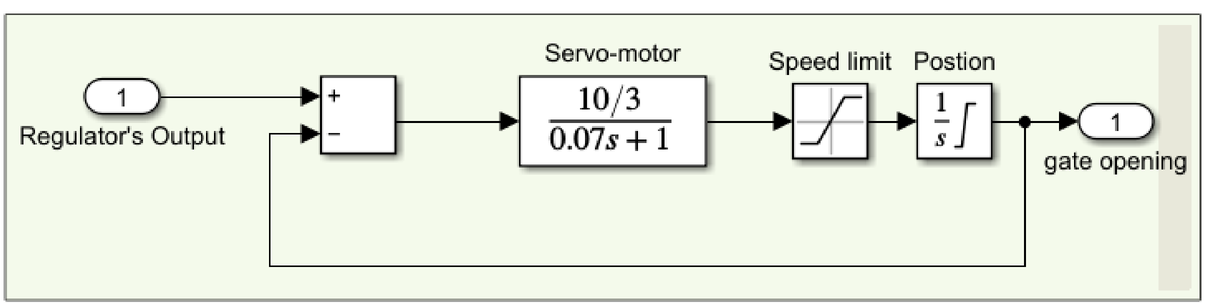


Figure 4. 12 Model of Gate Servomotor

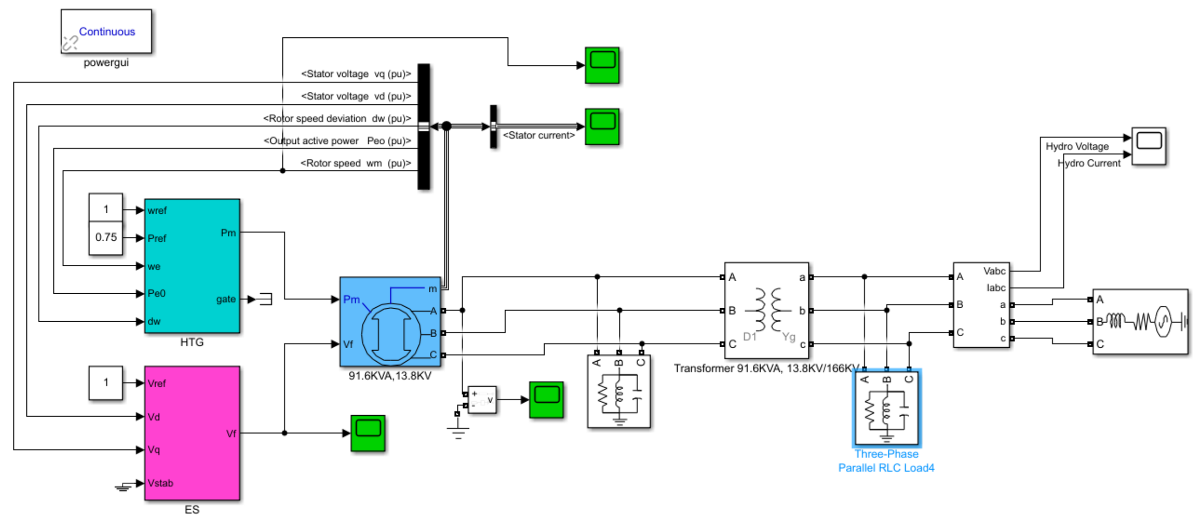


Figure 4. 13 Simulation Model of Hydro Power Plant Using Matlab/Simulink

Simulation Results: The generating voltage has been 13.8KV with active power is 73.3Kw. Figures 4.15 to Figure 4.18 shows the performance of the modeling of the micro hydropower plants. Figure 4.15 shows the result for Micro-hydro power plant current and voltage waveforms. Figure 4.16 shows the field voltage characteristics of the synchronous generator. It shows that the field voltage per unit takes 0.08 seconds to reach steady state condition. The stator current of the synchronous generator as shown in Figure 4.17. In Figure 4.18, it is clear shown that the phase voltage of the synchronous generator.

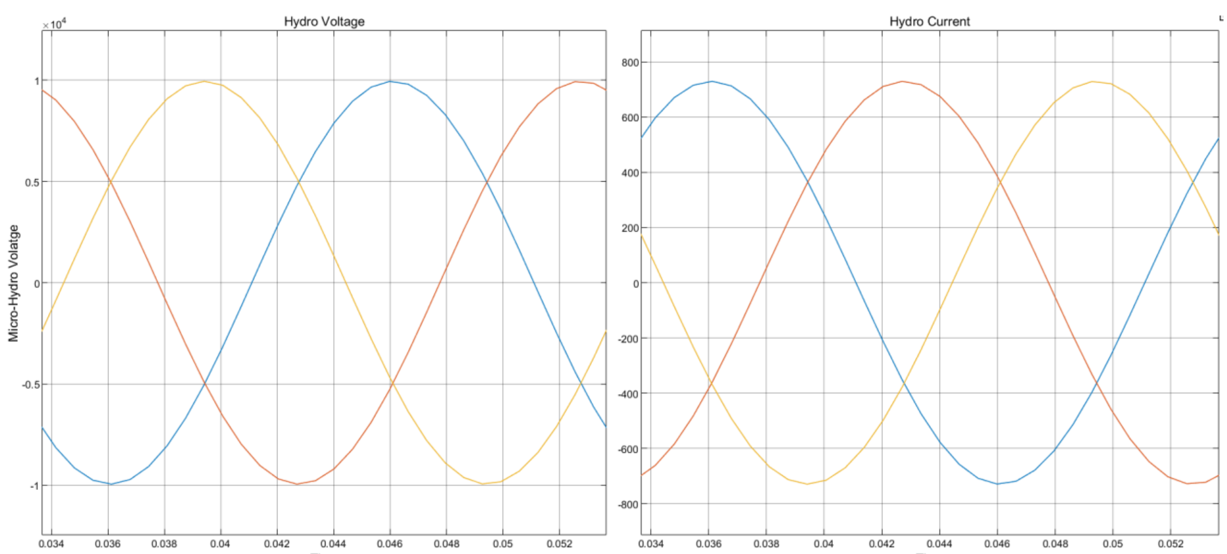


Figure 4. 14 The Micro-hydro Power Current and Voltage Waveforms

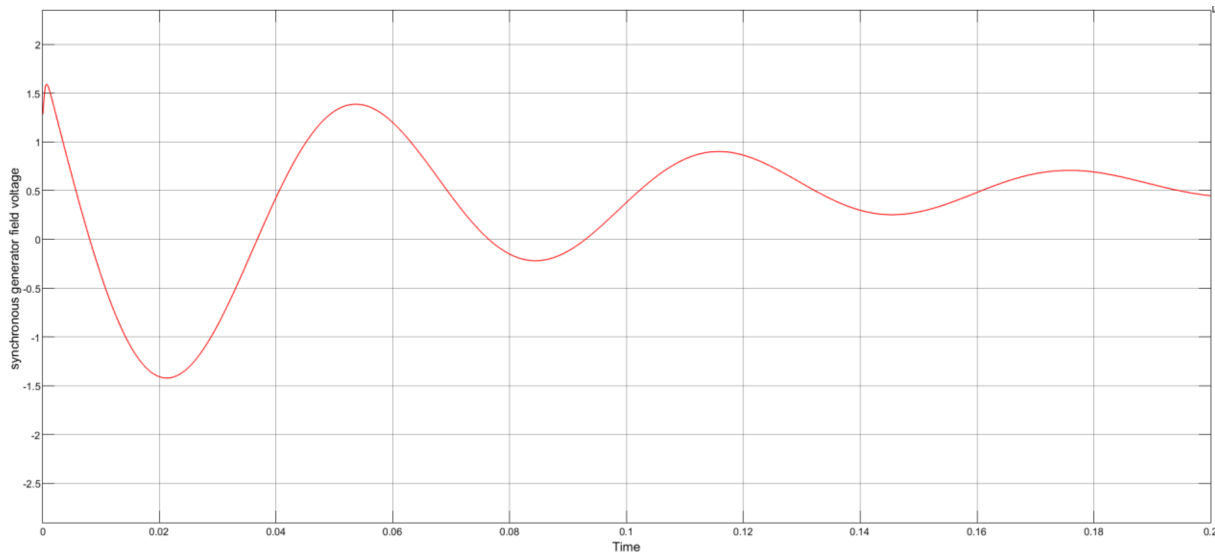


Figure 4. 15 the synchronous generator field voltage characteristics

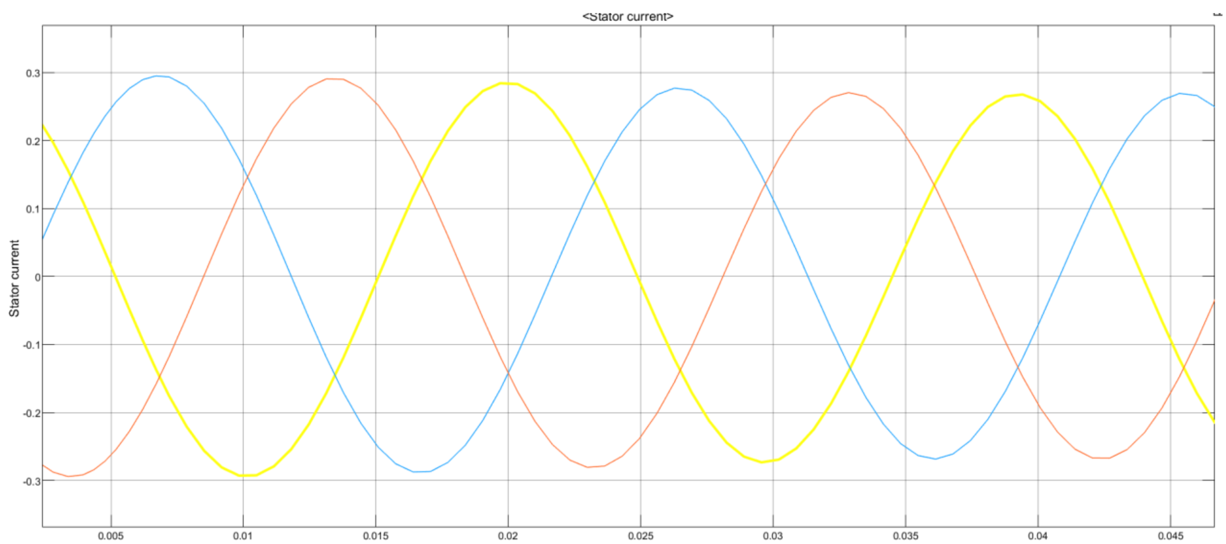


Figure 4. 16 the stator current of synchronous generator characteristics

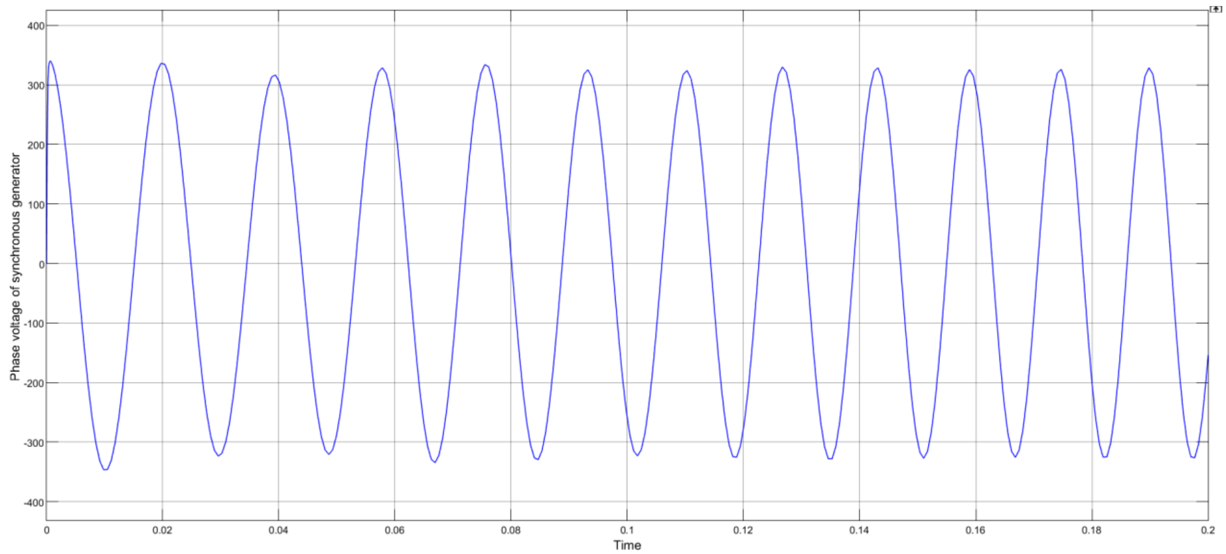


Figure 4. 17 The Phase voltage of synchronous generator characteristics

4.3.3 Simulation Model of Diesel Generator Using Matlab/Simulink

The diesel generator used as backup power supply, which has a capacity of 15Kw simulation is shown in the Figure below and the Speed will be controlled using PID controller.

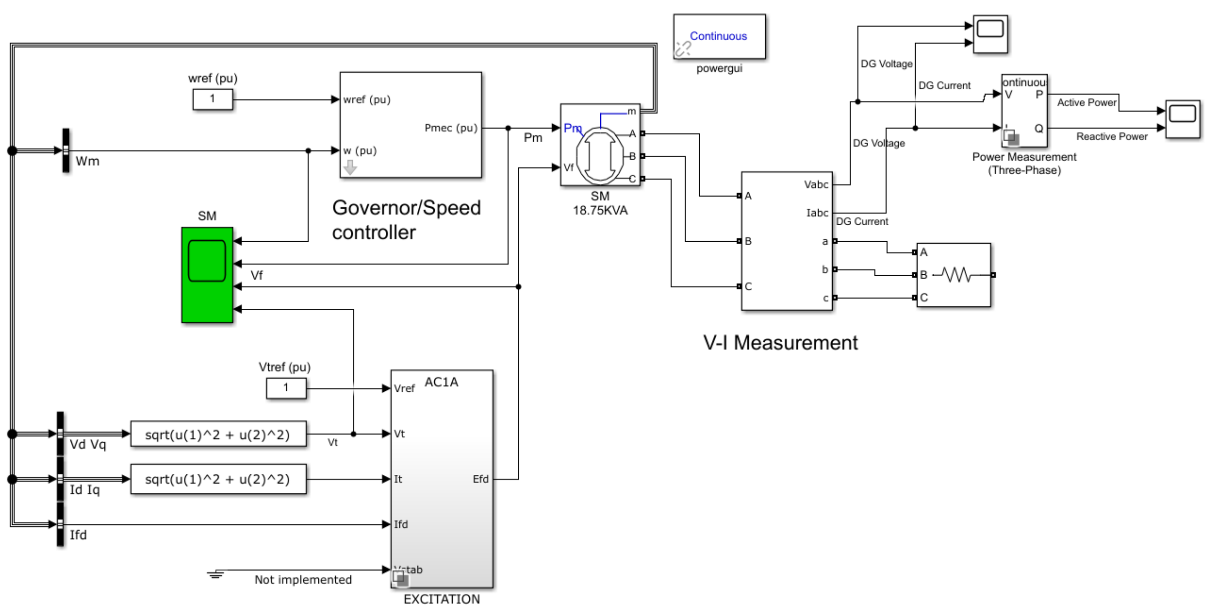


Figure 4. 18 Diesel generator modeling in Matlab/Simulink

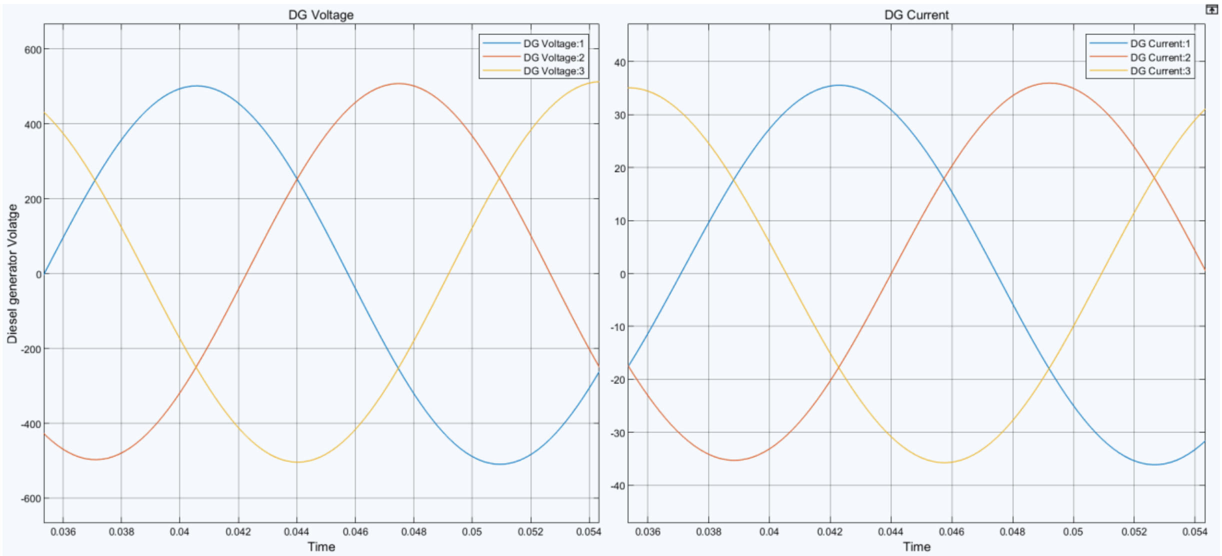


Figure 4. 19 diesel generator Current and Voltage waveforms

4.3.4 Overall system Modelling

The proposed hybrid system consists a micro-hydro, solar, and diesel technology as a backup, in which the energy to be produced from these renewable energy resources. The overall the system modeling in Matlab –Simulink as shown in figure 4.16 below including the output Voltage and current sine wave shown in Figure 4.17

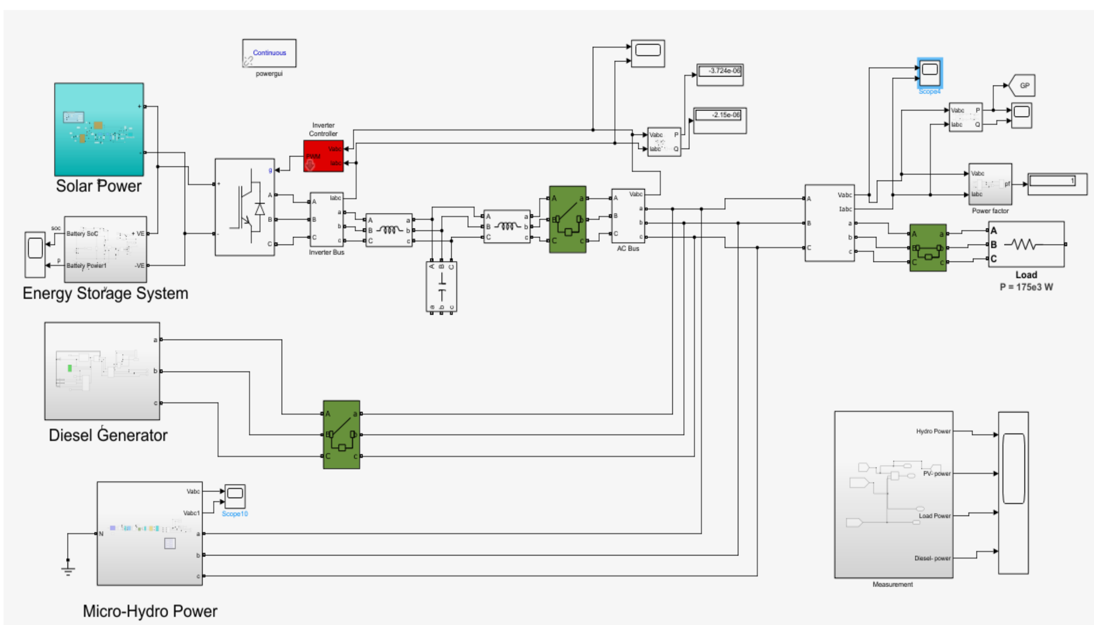


Figure 4. 20 Hybrid Power system modeling in Matlab-Simulink

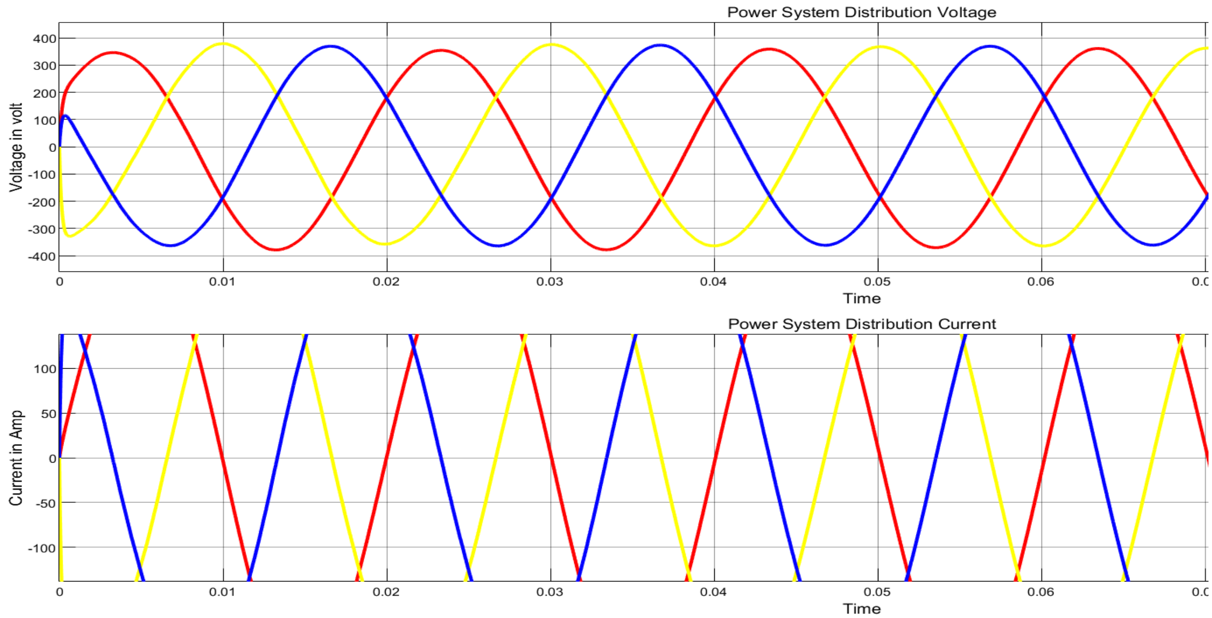


Figure 4. 21 Voltage and current simulation result

4.3.5 Fuzzy Logic Controller

The fuzzy logic controller has four variable inputs, namely demand power (Pd), Micro-Hydro power (Hp), solar power (Sp) and Diesel generator (DP), but one crisp output power (Po).

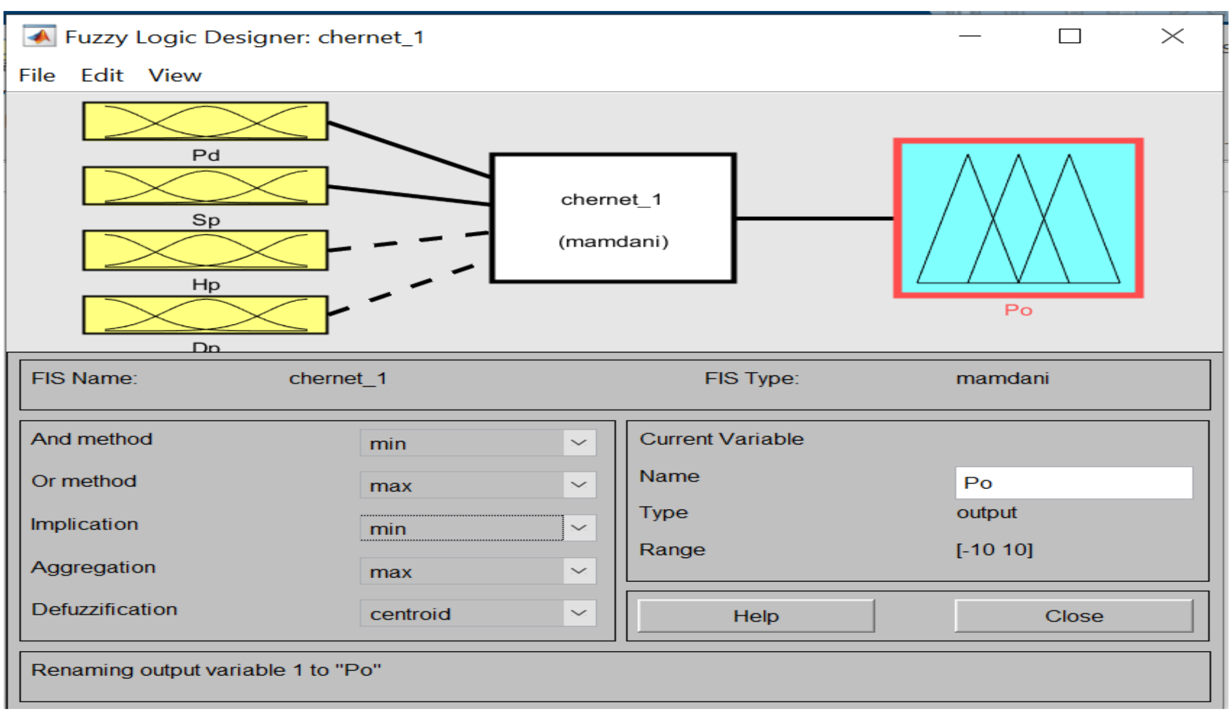


Figure 4. 22 MATLAB implementation of the Fuzzy logic control system

4.3.5.1 Member Functions

a. **Membership Function of Demand Power, Pd**: The demand power is one of the input linguistic variables having three linguistic variables called energy_demand_low = fuzz.trimf(energy_demand, [0, 0, 500]), energy_demand_medium = fuzz.trimf(energy_demand, [0, 500, 1000]), and energy_demand_high = fuzz.trimf(energy_demand, [500, 1000, 1000]). (figure-4.19)

b. **Membership Function of Main Power, Hp**: micro_hydro_low = fuzz.trimf(micro_hydro_output, [0, 0, 50]), _hydro_medium = fuzz.trimf(micro_hydro_output, [50, 61.65, 73.3]), and micro_hydro_high = fuzz.trimf(micro_hydro_output, [73.3, 90, 100]). (figure-4.20)

c. **Membership Function of Solar Power, Sp:** solar_low = fuzz.trimf(solar_output, [0, 0, 30]), solar_medium = fuzz.trimf(solar_output, [30, 37.5, 45]), and solar_high = fuzz.trimf(solar_output, [45, 60, 50]). (figure-4.21)

d. **Membership Function of Diesel generator Power, Dp** : diesel_low = fuzz.trimf(diesel_output, [0, 0, 5]),diesel_medium = fuzz.trimf(diesel_output, [5, 10, 15]), and diesel_high = fuzz.trimf(diesel_output, [15, 25, 30]). (figure-4.22)

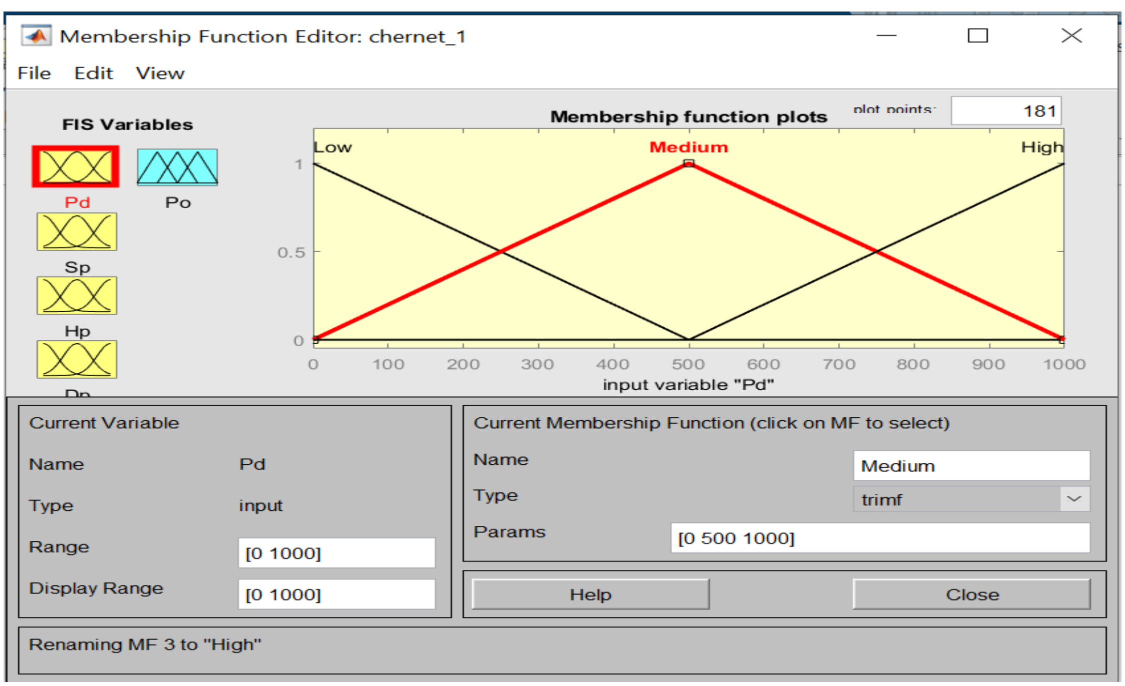


Figure 4. 23 Membership Function of Demand Power, Pd

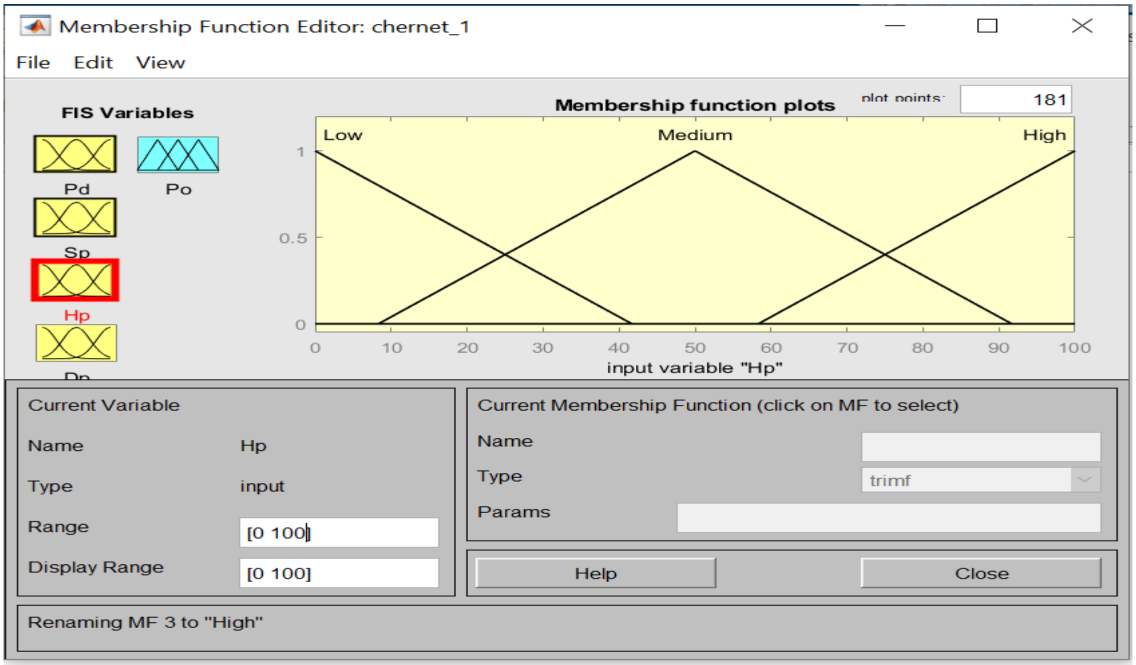


Figure 4. 24 Membership Function of Micro-hydro Power, Hp

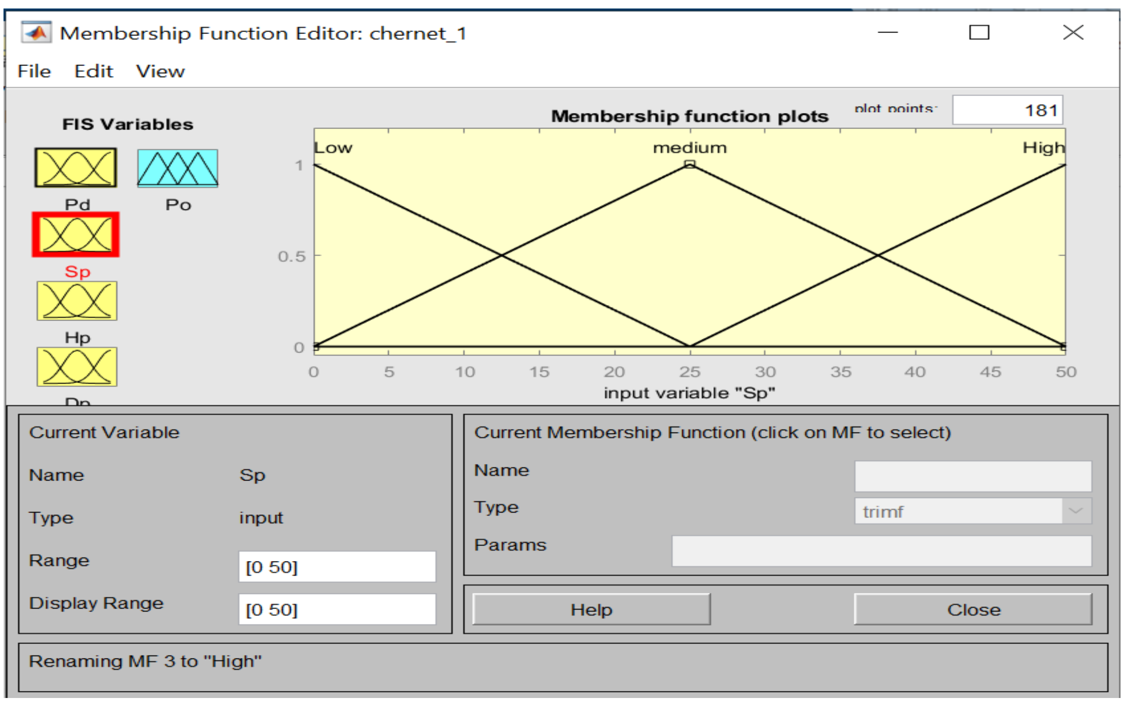


Figure 4. 25 Membership Function of Solar Power, Sp

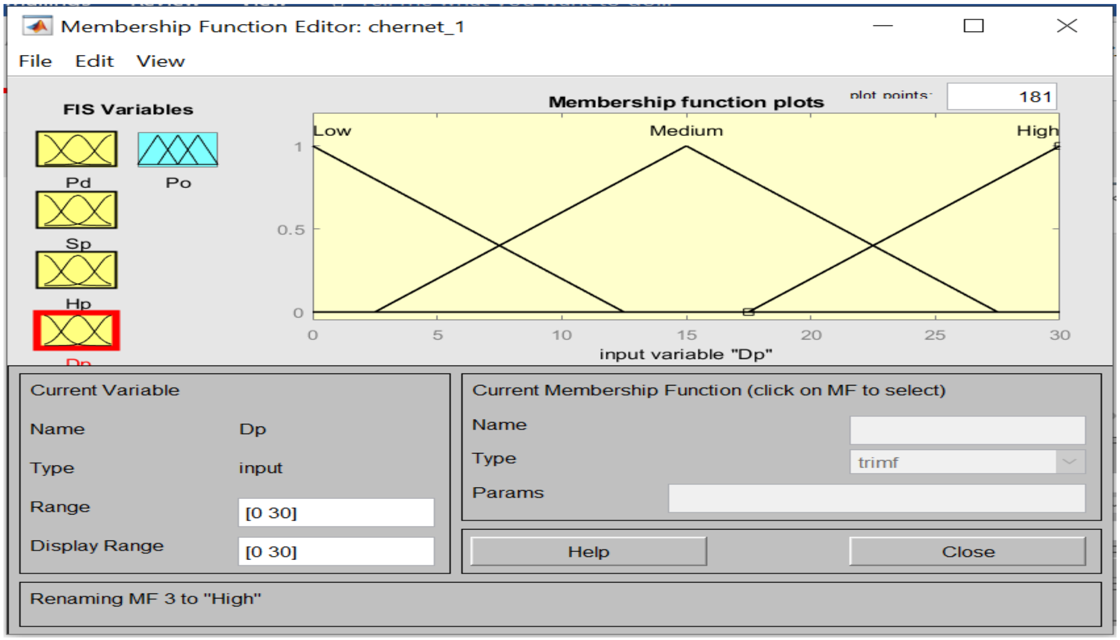


Figure 4. 26 Membership Function of Diesel generator, DP

e. **Membership Function of output power, Po**: The output power has Five linguistic values called Sp only, Sp + Hp , Sp + Dp , Sp + Hp + Dp , and Hp only . (figure-4.24)

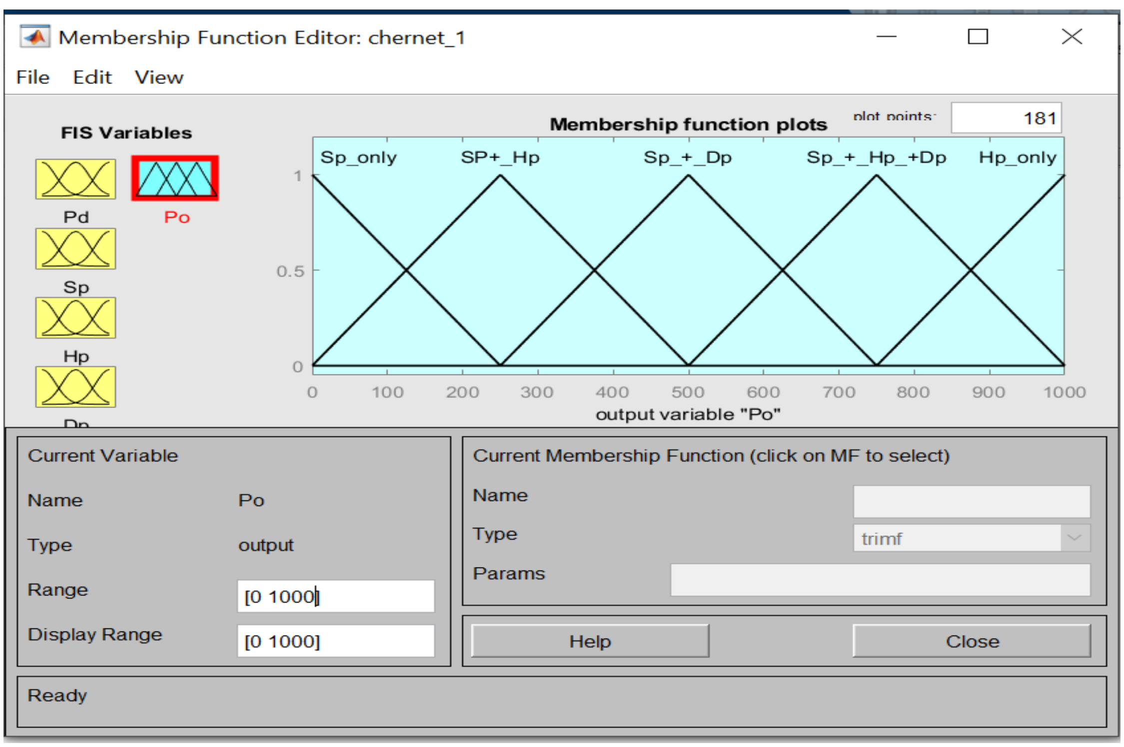


Figure 4. 27 Membership Function of Output Power, Po

4.3.5.2 Modelling of Fuzzy Logic Control Rules

Rules, and the overall system model is operated in accordance these rules, written in the rule editor.

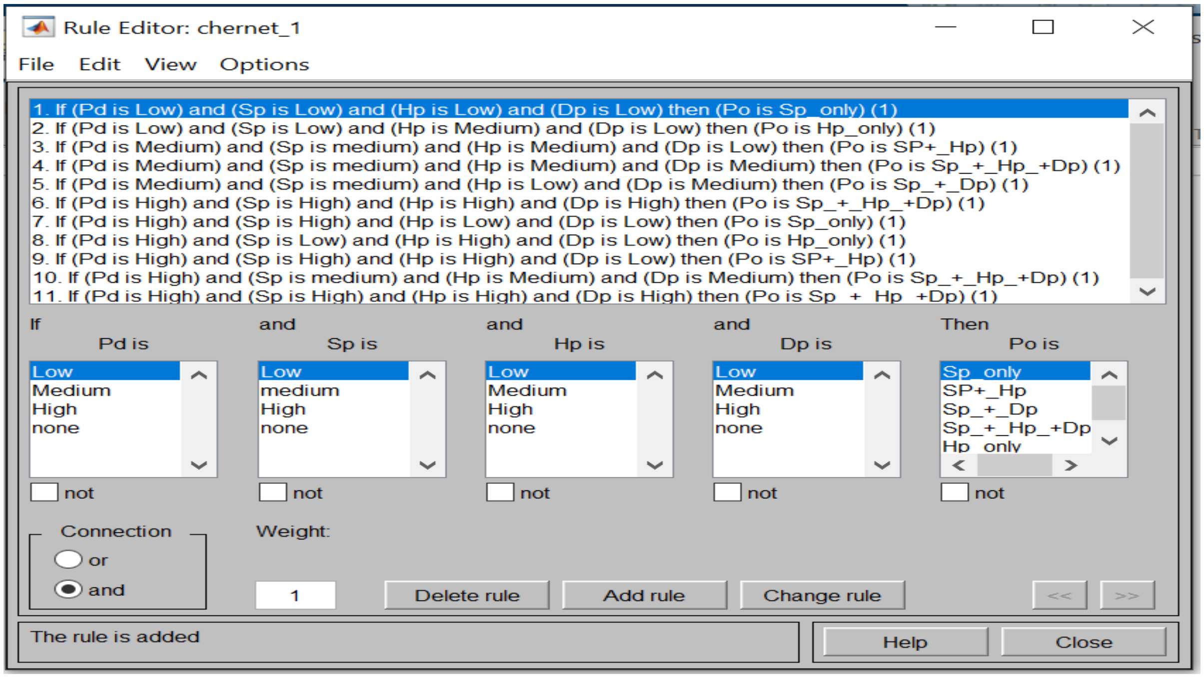


Figure 4. 28 Fuzzy logic rule editor view

In Matlab, there is an opportunity to view if the system is operating in accordance the written rules, and below a typical example is given by deliberately making all the three alternative energy system. Namely, solar power, micro-hydro power, and diesel power, 41.1KW, 64,1KW, and 13.3 KW respectively; and according to this typical example, the decision is to supply the demand power which is around 750KW

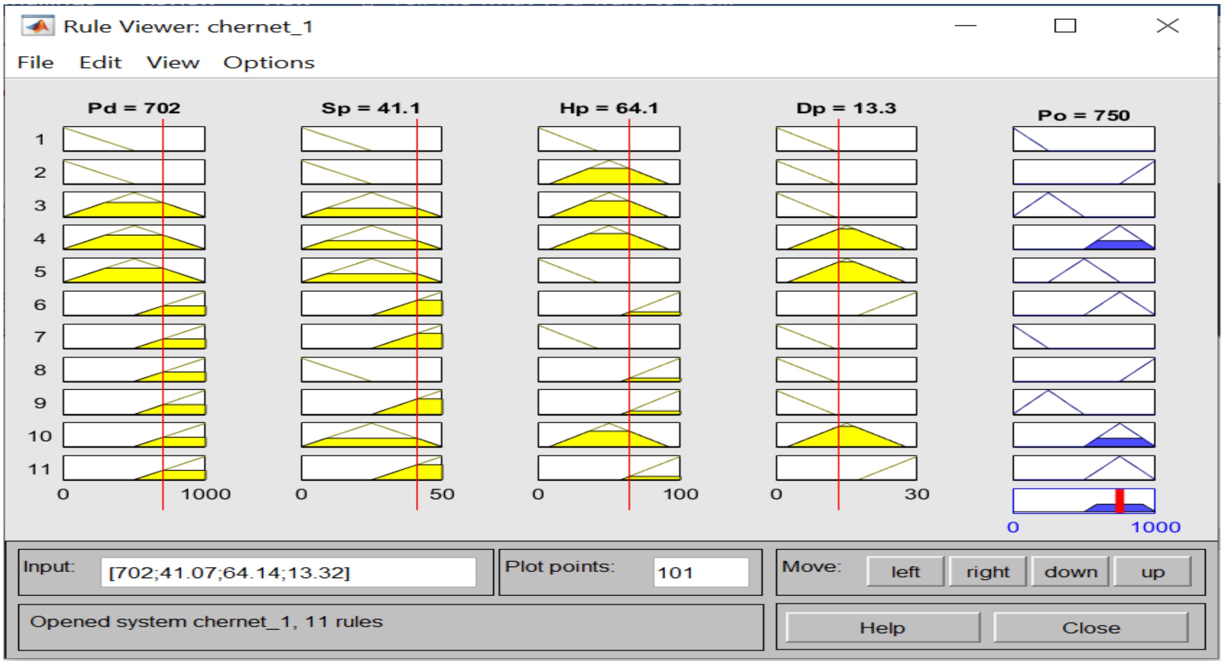


Figure 4. 29 Fuzzy logic rule viewer

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This study deals with a feasibility study and Optimal design of a Micro-hydro/PV/DG/battery Energy microgrid system with a technically feasible and cost-effective system configuration system for kola-Kinibibit kebele. The hybrid system designed to supply energy to the selected village solves energy needs in the village and improves the life of the community living in that area. The study of renewable energy potentials of the site is based on the recently recorded data of average solar radiation optioned from surface metrology (NASA-2021) and in the case of Hydro, the flow data obtained from MoWIE. The average monthly profile and hourly data for both sources were analyzed using Homer software. The result optioned from the software gave numerous alternatives of feasible hybrid systems with different levels of renewable resource penetration in which their choice was sorted by changing the net present cost of each system. From a technical point of view, a micro hydro/PV /DG/Battery hybrid system was selected in this study. From the simulation result, the majority of energy optioned from hydropower, which accounts for 83.1%, the PV module covers about 16.2%, and DG is only 0.717% of total load consumption. From an economic point of view, it is found that the village under study is characterized by average stream flow150l/s and solar radiation of 5.23kwh/m2 /day. The hybrid system cost competitive with $0.0966/kWh, is somehow affordable. From an environmental standpoint, the renewable energy fraction of the project is 99.1%, which implies the total energy almost obtained from renewable energy sources. This study, generating clean energy and its contribution to the reduction of pollutant emissions released to the environment. Generally, this study contributes to minimizing environmental pollution, deforestation, and soil degradation due to this, people use firewood, cow dung, other traditional biomass resources, and kerosene, which is difficult to afford. The hybrid power system would be controlled using fuzzy logic membership phenomena. Finally, it can be concluded that this hybrid power system is the preferred solution due to its technically and economically feasible and Environmentally Friendly Configuration

5.2. Recommendation for Future Work

Energy is very crucial to accomplish various activities in human beings. Thus, to improve energy crises at the country level, Off-grid renewable energy system is Contributed using different mechanisms including subsidies. Giving due- merit to environmental pollution, land degradation, poor life quality of the rural community, and generating renewable resources should be implemented. However, the current electrification in Ethiopia is by building large hydro dams rather than building a micro-grid system. This constructing hydro dam could not fully cover the energy requirement of the country.

- The government and concerned bodies should give due attention to the combination of Micro Hydro and PV which is cost-effective; provide 24-hour quality electricity for rural electrification.
- This study area was selected randomly from the village of Gera district in the Oromia region and it is not overall Oromia regions. For Feature, the researcher should conduct to investigate other Micro Hydro potential sites and solve energy crises in Ethiopia's rural areas.
- Most of the rivers in Ethiopia are not gauged which makes finding relevant data difficult. Therefore, it is recommended the concerned governmental body to give due attention to this work.
- The essential points revealed by this analysis are that developing this power production in the village requires government subsidies to make the service affordable to the consumer. In addition to this, the active involvement of local people to maintain the system is very important to reduce operating and maintenance costs.
- Fuzzy logic membership function is used to controlled or managed the hybrid power system, but ANFIS is the most popular, therefore any researcher he/she can use the mentioned controller system.

References

0. Gang Liu, M. R. (2012). *Techno-economic simulation and optimization of residential grid-connected PV system for the Queensland climate; Renewable Energy.*

A., T. (2011). *Tekle A. (2011), experimental Investigation on performance characteristics and efficiency of electric Injera baking pans, (Mitad) " (Doctoral dissertation, AAU).*

AK Akella, R. S. (2010). *AK Akella, RP Saini, and MP Sharma (2010), Sizing and cost analysis for integrated renewable .*

Ashok, S. (2007). *'Optimized model for community-based hybrid energy system', Renewable Energy 32 (7), pp. 1155-64.*

Ashok, S. (2007). *Ashok, S. (2007) 'Optimized model for community-based hybrid energy system', Renewable Energy 32 (7), pp. 1155-64.*

Ayodele, T. R. (2014). *Mathematical methods and software tools for designing and economic analysis of hybrid energy system. International Journal of Renewable Energy, 9(1), 57-68.*

Ayodele, T. R. (2014). *Mathematical methods and software tools for designing and economic analysis of hybrid energy system. International Journal ofRenewable Energy, 9(1), 57-68.*

Ayodele, T. R. (2014). *Ayodele, T. R., & Ogunjuyigbe, A. S. O. (2014), Mathematical methods and software tools for designing and economic analysis of hybrid energy system. International Journal of Renewable Energy, 9(1), 57-68.*

Bhandari, B. L. (2014). *Bhandari, B., Lee, K. T., Lee, C. S., Song, C. K., Mackey, R. K., & Ahn, S. H. (2014). A novel off-grid hybrid power system comprised of solar photovoltaic, wind, and hydro energy sources, applied energy, 133, 236-242.*

Book. (1998). *Installing photovoltaic systems A Question and Answer Guide for Solar Electric Systems.*

Book. (2015). *Bureau of Energy Efficiency, Application of Non-Conventional and Renewable .*

Book, E. 2. (2000). *ESMAP, 2000a: Mini-Grid Design Manual; ESMAP Technical Paper No. 007, The World Bank,Washington,Washington,D.C.,USA,September2000;in:http://www.worldbank.org/serv let/WDSContentServer/WDSP/IB/2000/12/15/000094946_00112305412326/Rendered/*

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bookk. (n.d.). *Lovisa Bergman and Amanda Enocksson, Design of PV system with variations of hybrid system at Addis Ababa institute of Technology.*

Bryan, R. C. (2013). *Bryan, R. C. and Sharp, K. V.: "Impulse turbine performance characteristics and their impact on Pico-hydro installation", Renewable Energy Journal, Elsevier, Vol. 50, pp. 959-964, 2013.*

Cook, G. F. (1998). *G. Forrest Cook (1998), Solar Charge Controller for Medium Power Applications.*

Diaf, S. B. (2008). . *Diaf, S., Béchamel M., Haddadi, M., Louche, A. (2008), 'Technical and economic assessment of hybrid PV/wind system with battery storage in Corsica Island', energy policy 36.*

Girm, Z. (2015). *Zelalem Girma (2015), Techno-Economic Feasibility of Small Scale Hydropower in: The Case of the Kulfo River, in Southern Ethiopia.*

Hadwan and A. Alkholidi, ". (2016). *Solar power energy solutions for Yemeni rural villages and desert communities," Renew. Sustain. Energy Rev., vol. 57, pp. 838–849, .*

Homer. (2009). *HOMER® Pro, (2009), Version2.68 User Manual.*

HYRESS. (2008). *hybrid Renewable Energy Systems for Supplying of Services.*

HYRESS. (2008). *HYRESS, (2008), hybrid Renewable Energy Systems for Supplying of Services.*

Ishaq M., I. U. (2013). *Ishaq M., Ibrahim U.H., Abubakar, H.(2013), Design Of An Off Grid Photovoltaic System: A Case Study Of Government Technical College, Wudil, Kano State , Volume 2, issue 12, issue 2277-8616.*

J.P.Sharma. (2015). *J.P.Sharma, Oct, 2015, A Standalone Hybrid Energy system modelling for Academic institution.*

John, R. (2001). *EEU, Universal Electric Access Program (UEAP). Electric Power Distribution Network Design and Construction Training Manual.*

Kimera, R. (2011). *Kimera, R. (2011), Consideration for a sustainable hybrid electric power mini-grid: case study for Wanale village in Uganda (Doctoral dissertation, University of Cape Town).*

Koutroulis, E. K. (2006). *'Methodology for optimal sizing of stand-alone photovoltaic/wind-generator systems using genetic algorithms', Solar Energy 80, pp. 1072-1085.*

L. Olatomiwa, R. B. (2018). *L. Olatomiwa, R. Blanchard, S. Mekhilef, and D. Akinyele, "Hybrid renewable energy supply for rural healthcare facilities: An approach to quality healthcare delivery," Sustain. Energy Technol. Assessments, vol. 30, no. February, pp. 121–138, 2018.*

L. Olatomiwa, R. B. (2018). *L. Olatomiwa, R. Blanchard, S. Mekhilef, and D. Akinyele, "Hybrid renewable energy supply for rural healthcare facilities: An approach to quality healthcare delivery," Sustain. Energy Technol. Assessments, vol. 30, no. February, pp. 121–138, 2018.*

link. (n.d.). *https://energypedia.info/wiki/Ethiopia_Energy_Situation#Hydropower*.

Mutasim Nour, G. R. (2014). *Mutasim Nour, Golbarg Rohani (2014), Prospect of Stand-Alone PV-Diesel Hybrid Power System for Rural Electrification in UAE.*

Mutasim Nour, G. R. (2014). *Mutasim Nour, Golbarg Rohani (2014), Prospect of Stand-Alone PV-Diesel Hybrid Power System for Rural Electrification in UAE.*

N. Argaw, R. F. (2001). *New Mexico State University Las Cruces, New Mexico, Renewable Energy for Water Pumping Applications in Rural Villages, .*

N., T. (2015). *Taken from Tilahun N., data gathered during site observation (2015) for the purposes of turbine development.*

Nasir, i. A. (2013).

NREL. (2016). *National renewable energy laboratory (NREL2016).*

O. Oladigbolu, M. A.-t. (2019). *O. Oladigbolu, M. A. M. Ramli, and Y. A. Al-turki, "TechnoEconomic and Sensitivity Analyses for an Optimal Hybrid Power System Which Is Adaptable and E ff ective for Rural Electrification : A Case Study of Nigeria," Sustain., 2019.*

Odax Ugirimbabazi, M. t. (2015). *Odax Ugirimbabazi, Master thesis (2015), Analysis of Power System Options for Rural Electrification in Rwanda.*

Ouma, C. A. (2011). *, Hybrid Energy System for Off – Grid Rural Electrification" .*

Penick, T. a. (December 4, 1998). *Photovoltaic Power Generation.*

R.K.Behl, R. S. (2013). *Renewable Energy Sources and Their Applications.*

Roger A. Messenger, J. V. (2010). *Photovoltaic Systems Engineering, 3rd ed. New York: CRCPress* . New York.

Roger A. Messenger, J. V. (2010.). *Photovoltaic Systems Engineering, 3rd ed. New York:*

CRCPress .

Salisu, M. W. (2019). *Salisu, M. Wazir, and L. Olatomiwa, "Assessment of technical and economic feasibility for a hybrid PV-wind-diesel-battery energy system in a remote community of north central Nigeria," Alexandria Eng. J., 2019.*

Singh, D. (2009). *Micro hydropower resource assessment handbook Economic and social* .

T., B. (2011). *Bizuayehu T. Master Thesis (2011), Improved Sustainable Power Supply for Dagahabur and Kebridahar Town of Somalia Region in Ethiopia, School of science and technology at Reykjavik University.*

Taken from Tilahun N. (2015). *Data gathered during site observation for the purposes of* .

Teshale, A. (2012). *Modelling and simulation of fuzzy logic based hybrid power forirrigation system in case of wonji-shoa villages.*

Tsegaye, S. (2016). *Samson Tsegaye (2016), Country Director, Solar Energy Foundation, Ethiopia June 27-29.*

Tsegaye, S. (2016). *Samson Tsegaye (2016), Country Director, Solar Energy Foundation, Ethiopia June 27-29.*

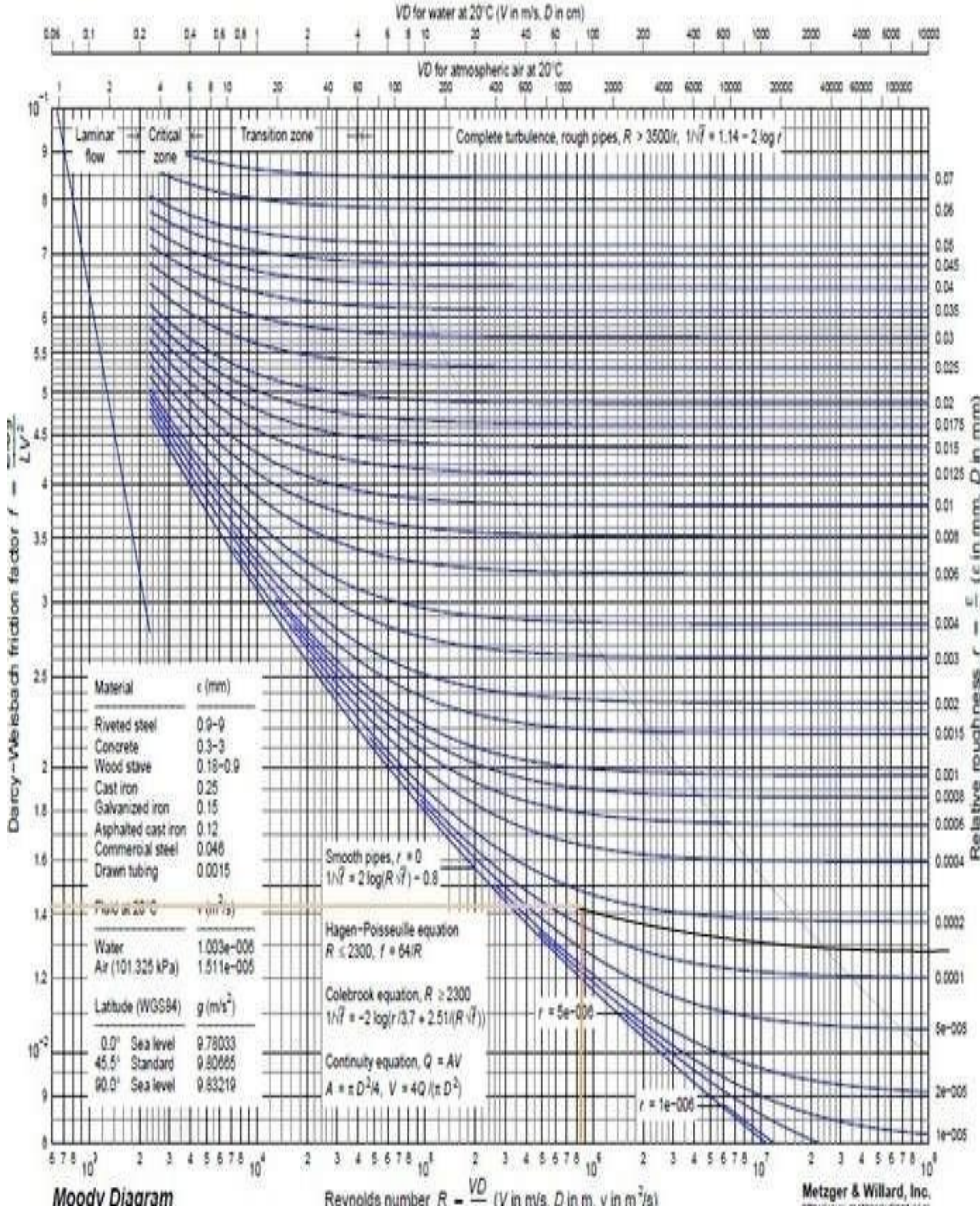
Version, H. P. (2016). *HOMER® Pro Version 3.7 User Manual, (2016), HOMER® Energy 1790 30th St Suite 100 Boulder CO 80301 US.*

Appendix

Appendix A: The village load demand after power and population projection

Period	20% of Total HH load(kWh/d)	80% of Total HH load(kWh/d)	School load (kWh/d)	Health post load (kWh/d)	Church Mosque load (kWh/d)	Municipal Load(Kwh/d)	Small-Scale Load(KWh/d)	Commercial (kWh/d)	Total load
00:00-1:00	0	0	0	0.06	0			2.15	2.21
1:00-2:00	0	0	0	0.06	0			2.15	2.21
2:00-3:00	0	0	0	0.06	0			2.15	2.21
3:00-4:00	0	0	0	0.06	0			2.15	2.21
4:00-5:00	0	0	0	0.06	0			2.15	2.21
5:00-6:00	0	0	0	0.06	0			2.15	2.21
6:00-7:00	82.215	6.211	0	0.06	0	2.965		0	91.451
7:00-8:00	82.215	6.211	0	0.06	0	2.965		0	91.451
8:00-9:00	10.611	12.13	0.1	1.27	0.1		7.81	5	37.021
9:00-10:00	10.611	12.13	0.1	1.27	0.16		7.81	5	37.081
10:00-11:00	10.611	12.13	0.1	1.27	0.16			5	29.271
11:00-12:00	10.611	12.13	0.1	1.27	0.12			5	29.231
12:00-13:00	10.611	12.13	0	0.06	0			0	22.801
13:00-14:00	10.611	12.13	0.1	0.25	0			5	28.091
14:00-15:00	10.611	12.13	0.1	0.25	0			5	28.091
15:00-16:00	10.611	12.13	0.16	0.27	0		7.81	5	35.981
16:00-17:00	10.611	12.13	0.16	0.25	0		7.81	5	35.961
17:00-18:00	146.937	12.13	0.25	0.27	0.43			0	160.017
18:00-19:00	156.353	18.5	0	0.06	0			0	174.913
19:00-20:00	9.396	23.41	0.25	0.27	0.43			1	34.756
20:00-21:00	10.611	28.9	0.25	0.14	0.37			1	41.271
21:00-22:00	9.396	23.41	0	0.14	0			1	33.946
22:00-23:00	6.966	23.41	0	0.14	0			1	31.516
23:00-00:00	6.966	23.41	0	0.14	0			1	31.516
Total	**606.554**	**274.8**	**1.67**	**7.8**	**1.77**	**5.93**	**31.24**	**57.9**	**987.626**

Appendix B: Moody diagram and Typical value of surface roughness



Appendix C: Manning coefficient np for several commercial pipes

http://indmicrohydro.blogspot.com/2010/05/manning-coefficient-nfor-several.html

Types of Pipe	np
Welded steel	0.012
Polyethylene(PE)	0.009
PVC	0.009
Asbestos cement	0.011
Ductile iron	0.015
Cast iron	0.014
Wood-stave(new)	0.012
Concrete (steel forms a smooth finish)	0.014

Appendix D: Head loss and penstock diameter calculation.

Step1: Penstock diameter calculation:

Dp = 2.69 $(np^2 * Q^2 * Lp/Hg)^{0.1875}$, np=0.012, Q= 0.15$m^3$/s, Lp= 60m, Hg=60m. Dp= $2.69(0.012^2 * 0.15^2 * 60/80)^{0.1875}$ = 0.254m.

Step 2: Cross-section area of penstock of pipe (m^2) calculation:

Ap= $\pi r^2 =$ 3.14× (0.254)2 /4.0 =0.0467m^2,

Step3: Velocity, Vp= Qp/Ap = 0.15/0.0467= 3.2m/s .

Step4: The Reynolds number "Re" is calculated as follows

Re= V*D/v, where V=3m/s, D is the length of penstock (60m), and v= $1.004x10^{-6,}$ Reynolds number of 7.6x105 and calculated relative roughness is ∈/D =0.046/254 = 0.00015, Based on the relative roughness (0.00015), we can get friction factor 0.013 from Moody chart

Step 5: head loss calculation, hl= f*lp/dp *vp^2/2.g = 1.41m

Appendix E: Pelton-Turbine Type design parameters calculation:

Step 1: Turbine speed: $N = \frac{60*w}{2\pi}$ = 739 rpm, and the Specific speed is Ns= N*$\int Pt$/$H^{5/4}$ = 31.58 rpm. If the runner speed (N), the net head, and the water flow rate (Q) is known, the dimensions of the Pelton turbine can be estimated from the following equations [6]:

Step 2: Determination of diameter of the circle describing the bucket's center line in meters.

D1= $40.8* \frac{\sqrt{Hn}}{N}$, it was proposed that the Pelton two nozzle of the turbine, then bucket width in meters will be B1= $\int \frac{Q}{K} * 1/\int Hn$ = 2.8m, nozzle diameter in meters, which is De= $\int \frac{Q}{K} * 1/\int g * Hn$=5.41m, jet diameter in meters. D=$\int \frac{Q}{\int Hn}$ = 4.09m, and jet velocity (m/s).Vjet=$\int 2gHn$ = 39m/s.

Step 3: Range of specific speed and head

Table E.1 Range of specific speed and head

Turbine type	Range of Specific speed (r.p.m)	Turbine type	Range of head (meter)
Pelton one nozzle	5 ≤N≤25	Kaplan and propeller	2<Hn<40
Pelton two nozzle	7 ≤N≤35	Francis	10<Hn<350
Pelton four nozzle	10 ≤N≤50	Pelton	50<Hn<1300
Cross-flow	20 ≤N≤200	Cross-flow	3<Hn<200
Francis	50 ≤N≤300		
Kaplan & Propeller	20 ≤N≤1550		

Step 4- The ratio of runaway speed for different turbines

Table E.2 Ratio of runaway speed for different turbines

Turbine type	Normal speed (*r.p.m*)	Runaway speed (N max/N)
Kaplan single regulated	75-100	2-2.4
Kaplan double regulated	75-150	2.8-3.2
Francis	500-1500	1.8-2.2
Pelton	500-1500	1.8-2.0
Cross-flow	60-1000	1.8-2.0
Turgo	600-1000	2

Table E.3 Summarized turbine design, Governor, and pipe loss parameters result

Head loss calculation result			
Descriptions	**Unit**	**Value**	**Source**
Flow Rate (Q)	m^3/s	0.150	MOWEI
Gross head(Hg)	m	60	Site data
Pipe Inside Diameter (d_p)	m	0.254	Determined value
Pipe Length (L)	m	60	Site data
Pipe average velocity – V	(m/s)	3	Determined value
Head Loss – Pipe	m	1.41	>>
Calculated turbine design parameters			
Design parameters	**Unit**	**value**	**Source**
Turbine input power (P_{ti})	Kw	73.3	Determined value
Turbine speed (N)	rpm	739	>>
Turbine-specific speed (Ns)	rpm	31.88	>>
Number of turbine nozzles(Z)	N0	2	>>
Jet velocity (Vj)	m/s	29.8	>>
Runner circle diameter (D)	m	0.365	>>
Bucket width(B)	m	2.8	>>
Nozzle diameter(d_d)	m	5.41	>>
Jet diameter(d_s)	m	4.09	>>
Number of buckets(k_b)	N0	22	>>
D/B Ratio	-	3.6	>>

Hydraulic turbine and Control parameter			
Design parameters	**Unit**	**value**	**Source**
Rated generator power	KVA	91.6	Determined value
Rated turbine flow, qr	m^3/s	0.15	>>
Rated turbine head, hr	m	60	>>
Gate position at rated condition	Pu	0.9	>>
No load flow, q_{nl}	m^3/s	0.2	>>
Permanent droop, Rp	pu	0.05	>>
Temporary droop, Rt	Pu	0.8598	>>
The dashpot time constant, Tr	sec	11.0762	>>
Servo motor gain, ka		3.33	>>
Servo motor time constant, ta	sec	0.075	>>
Maximum gate opening rate	Pu/s	0.1	>>
Maximum gate closing rate	Pu/s	-0.1	>>
Maximun gate limit, Gmax	Pu	0.01	>>
Minimum gate limit, Gmin	Pu	0.97518	>>
Penstock cross-section Area, A	m^2	0.0467	>>
Turbine damping, D	pu	0.5	>>
Speed deviation, Δw	pu	0.77211	>>

Appendix F: 1. the most efficient solar panels offered by leading brands

Manufacturer	Model	Type	Module Efficiency
Sun Power	X21-345/335	Monocrystalline	21.5%
Ja Solar	JAC M6PA-4	Monocrystalline	20.9%
Sanyo	HIT Double 195	Monocrystalline	20.5%
Sun Power	327-320	Monocrystalline	20.4%
Sun Power	245-235	Monocrystalline	20.1%
Sun Edison	Silvantis R-Series	Monocrystalline	17.7%
Yingli Solar	YL225C-24b	Monocrystalline	17.1%
REC	Twinpeak Series	Monocrystalline	16.7%
Ja Solar	JAM6 48-220/SI	Monocrystalline	16.6%
Sun tech	STP265/WEM	Polycrystalline	16.3%
Trina	PA05	Polycrystalline	16.2%
Jinko Solar	JKM265P	Multicrystalline	16.2%
Canadian Solar	CS6P	Polycrystalline	15.9%
Yingli Solar	YL205P-23b	Multicrystalline	15.8%
Solar World	SW 260	Monocrystalline	15.5%
Sharp	NU-U23F1	Monocrystalline	14.4%
Yingli Solar	YL 235 P-29b	Polycrystalline	14.4%

Appendix G: The some optimization, from HOMER

Architecture						Cost				System			
PV (kW)	DG (kW)	Battery	Micro-Hydro (kW)	Converter (kW)	Dispatch	NPC ($)	COE ($)	Operating cost ($/yr)	Initial capital ($)	Ren Frac (%)	Cap Short (%)	Excess Elec (%)	Hours
45.1	15.0	160	73.3	126	LF	$862,098	$0.0966	$19,478	$375,151	99.1	1.09	11.6	269
50.5		192	73.3	130	LF	$862,506	$0.0966	$17,880	$415,513	100	1.06	12.4	
50.5		192	73.3	130	CC	$862,506	$0.0966	$17,880	$415,513	100	1.06	12.4	
48.8		200	73.3	133	LF	$862,637	$0.0966	$17,673	$420,808	100	1.09	11.9	
48.8		200	73.3	133	CC	$862,637	$0.0966	$17,673	$420,808	100	1.09	11.9	
49.4		200	73.3	132	LF	$863,171	$0.0967	$17,650	$421,918	100	1.06	12.0	
49.4		200	73.3	132	CC	$863,171	$0.0967	$17,650	$421,918	100	1.06	12.0	
49.1		192	73.3	135	LF	$863,460	$0.0967	$18,011	$413,178	100	1.05	11.9	
49.1		192	73.3	135	CC	$863,460	$0.0967	$18,011	$413,178	100	1.05	11.9	
49.9		192	73.3	133	LF	$863,573	$0.0967	$17,956	$414,673	100	1.03	12.2	
49.9		192	73.3	133	CC	$863,573	$0.0967	$17,956	$414,673	100	1.03	12.2	
52.0		192	73.3	128	LF	$863,854	$0.0968	$17,799	$418,868	100	1.06	12.9	
52.0		192	73.3	128	CC	$863,854	$0.0968	$17,799	$418,868	100	1.06	12.9	
52.3		192	73.3	128	LF	$863,942	$0.0968	$17,778	$419,492	100	1.07	13.0	

Appendix H: Questioners for Energy demand assessment of the village.

Table a) Household electric load

Appliances	Quantity	Capacity (W)	Run-time (h/d)	period
Low-energy lights				
TV electric load				
Radio electric load				
Cooking stove				
Enjera Backing machine				
Mobile charger				
Refrigerator				
Total				

Name of Respondent:______________________________________signature__________

Table b) School electric load

Appliances	Quantity	Capacity (W)	Run-time (hr/day)	remark
Classroom light				
Toilet room light				
External light				
Computer				
Printer				
Class- room- CFL				
Total				

Table c) Commercial electric load

Appliances	Quantity	Capacity (W)	Run-time (hr/day)	remark
Flour milling				
Tea shop				
Street light				

Table d) Health Center electric Load

Appliances	Quantity	watts (W)	Run-time (hr/day)	remark
Room lighting				
External light				
Toilet room light				
Communication radio				
Television				
Computer				
Printer				
Laboratory Microscope				
Vaccine freezer				
Total				

Name of Respondent:________________________Signature: _________________

Table e) Church electric Load/mosque

Appliances	Quantity	watts (W)	Run-time (hr/day)	remark
Megaphone				
Room lighting				
External light				
Computer				
Printer				
Total				

Name of Respondent:________________________________Signature: _________________